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Analysis of Sonic Anemometer Data From the CASES-99 Field Experiment

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Abstract

The Cooperative Atmosphere-Surface Exchange Study conducted near Leon, KS in October 1999 (CASES-99) is a multidisciplinary effort to study the interaction of the lower atmosphere with the land surface. Seven three-axis sonic anemometers from the U.S. Army Research Laboratory were deployed on five towers during the CASES-99 field campaign. Each of them has collected more than 100 hr of data. This report describes our data collection and processing details, and provides preliminary analyses from the intercomparison of sonic measurements. One of the interesting results of the intercomparison appears to be the microscale (on the order of 1 km) variability of wind field and turbulence characteristics, which is worthy of further study.

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1. Introduction

The Boundary Layer Meteorology and Aerosol Research Branch and the Acoustic and Electro-Optic Propagation Branch of the Battlefield Environment Division, Computational and Information Science Directorate, U.S. Army Research Laboratory (ARL) have participated in the Cooperative Atmosphere-Surface Exchange Study–1999 (CASES-99) near Leon, KS from 1 to 31 October 1999. This field experiment is a multidisciplinary effort to study the interaction of the lower atmosphere with the land surface. A description of the development of the CASES project, its field programs, and some early results has been provided by LeMone et al. (2000). An overview of the CASES-99 experimental design and its scientific goals have been provided by Blumen et al. (1999).

Seven three-axis sonic anemometers from ARL were deployed during the CASES-99 field program. The sonic anemometers were mounted on five towers. There were a total of 12 intensive observation periods (IOP) for the entire field experiment. Each IOP usually lasted from 1700 (Central Standard Time [CST]) through 0800 the next morning (about 15 hr). The ARL sonic anemometers collected data from IOPs 3–9. As a result, each of our seven sonic anemometers collected more than 100 hr of data relative to the three wind components and air temperature at a 10-Hz sampling rate. The collected sonic data have been carefully examined and processed. Computational results of turbulence statistics as well as mean quantities in the atmospheric surface layer have been obtained. Preliminary analysis from these results has also been carried out.

The objectives of this report are (1) to document the data collection and data processing from the ARL sonic anemometers, (2) to present the computational results, which can be used by other CASES-99 researchers, and (3) to provide important results from our analysis of the sonic data.

2. Data Collection and Processing

2.1 Brief Description of the CASES-99 Field Experiment

The CASES-99 experiment represents a second campaign to investigate linkages between the atmosphere and the Earth's surface in the south-central Kansas watershed described herein. It focuses on studying events in the nocturnal boundary layer and investigating the physical processes associated with evening and morning transition regimes. The CASES-99 main test site is a relatively small area, 4.8 × 3.2 km, near Leon, KS (50 km east of Wichita) (fig. 1). Its center is located at approximately 37.6501 latitude and –96.7438 longitude. The site was chosen for its relatively flat terrain and unobstructed vegetation. The terrain elevation runs from 1400 to 1450 ft above sea level (fig. 2). Participants included researchers from U.S. government agencies such as the Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), National Center for Atmospheric Research (NCAR), University Corporation for Atmospheric Research (UCAR), Argonne National Laboratory, and ARL; from universities such as the University of Colorado, University of Massachusetts, and University of Wyoming; and
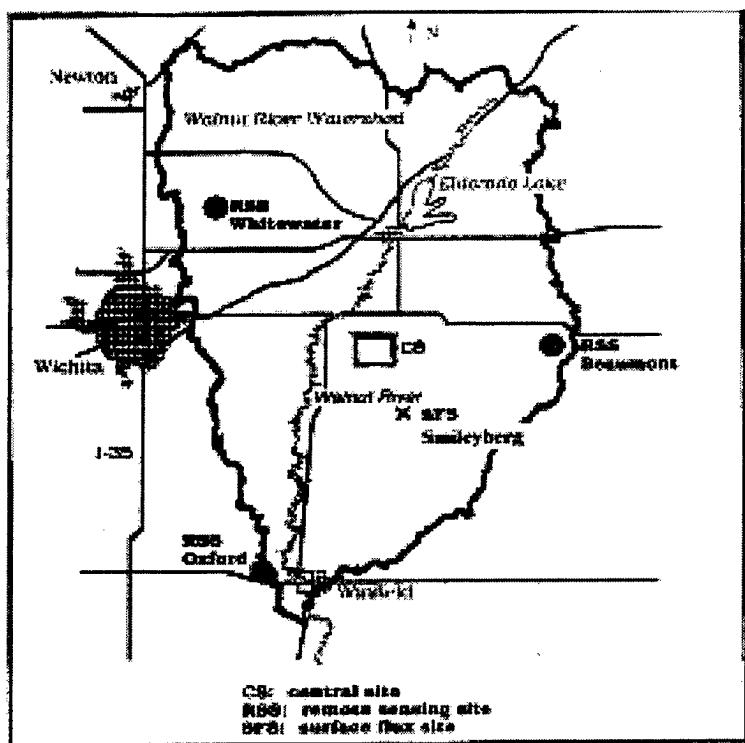
Figure 1. CASES-99 test site (central site [CS] area is enlarged below).
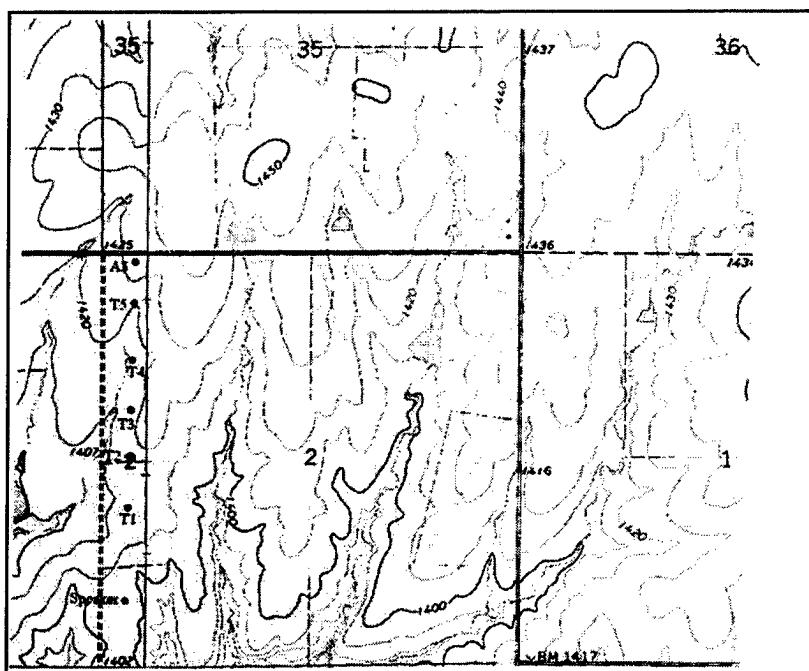
Figure 2. Terrain elevation of the CASES-99 CS.

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from European countries such as the Netherlands, Spain, Germany, and Denmark. Various instruments such as multiple radars, lidars, scintillometers, tethersondes, and rawinsondes were set up at a central 55-m main tower and on a distributed array of 10-m towers (fig. 3).
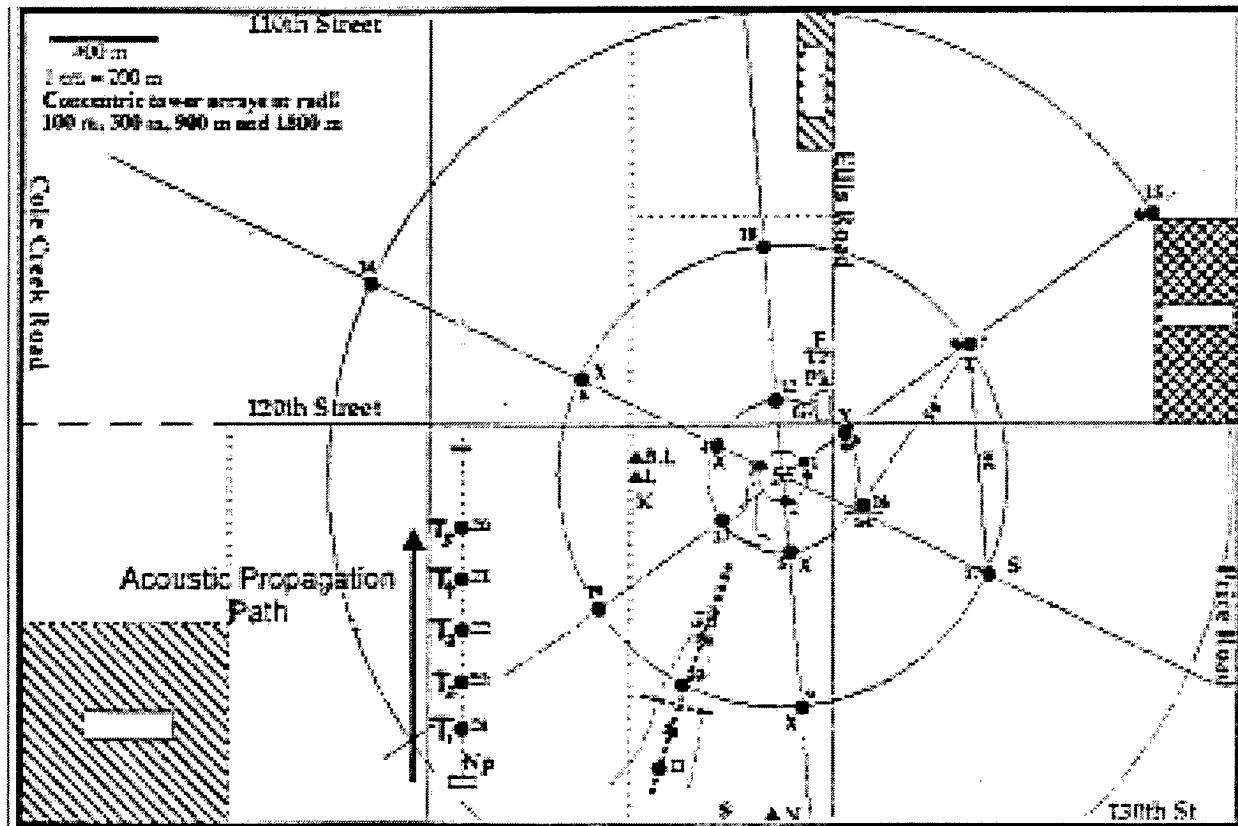
Figure 3. The CASES-99 instrument setup (T1–T5 are ARL's 5-m towers).

2.2 ARL Sonic Anemometer Deployment

During the CASES-99 field experiment, the ARL sonic anemometers were installed on five 5-m towers located about 1300 m to the west of the 55-m main tower (figs. 2–4). The 5-m towers were lined up in the North-South (N-S) direction and separated by approximately 200 m in between (fig. 5). They were labeled as T1, T2, T3, T4, and T5. There were two sonic anemometers mounted at 5 m above ground level (AGL) on towers T3 and T5, and five sonic anemometers, one for each tower, mounted at 2 m AGL. The sonic anemometers were carefully aligned on the towers and faced eastward. A photograph of the 5-m towers' deployment is shown in figure 4. Their exact locations are listed as:

Tower T1: N 37 deg 38' 27.6" W 96 deg 45' 4.2"   Elev: 1410 ft

Tower T2: N 37 deg 38' 34.3" W 96 deg 45' 4.0"   Elev: 1410 ft

Tower T3: N 37 deg 38' 40.6" W 96 deg 45' 3.7"   Elev: 1410 ft

Tower T4: N 37 deg 38' 47.0" W 96 deg 45' 3.6"   Elev: 1415 ft

Tower T5: N 37 deg 38' 54.2" W 96 deg 45' 1.9"   Elev: 1435 ft

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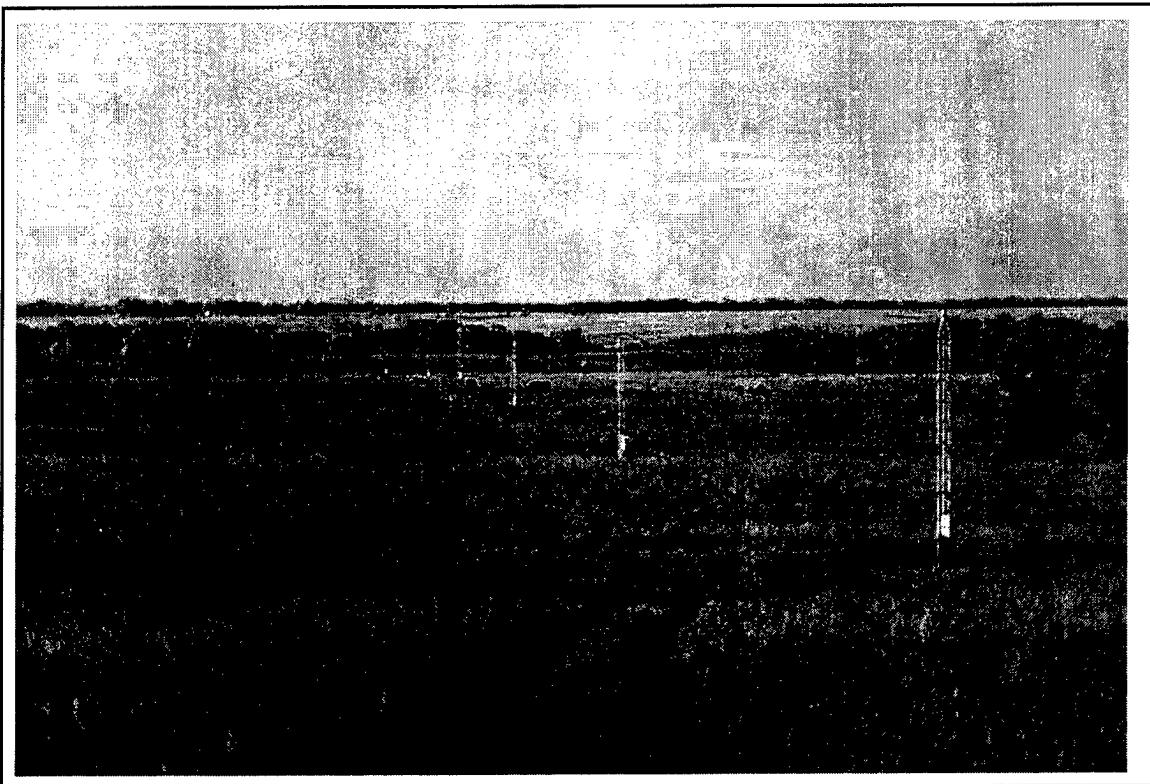
Figure 4. A photograph of 5 towers lining up in the North-South (N-S) direction.
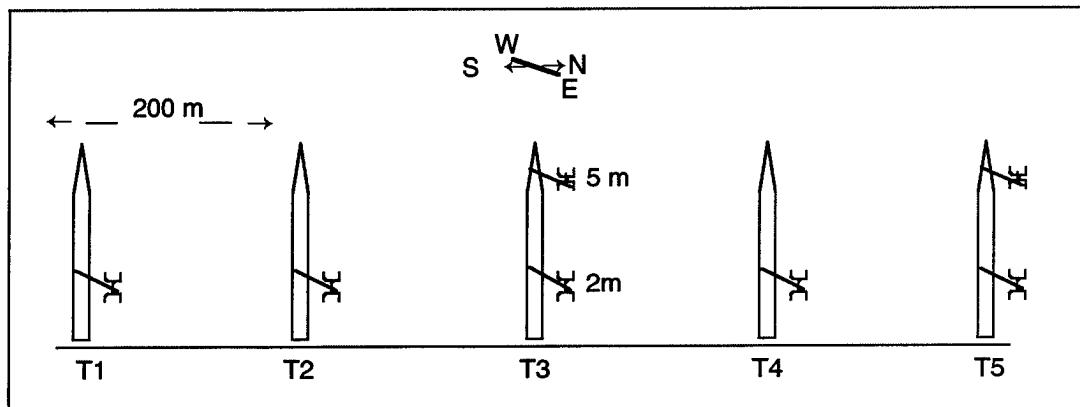
Figure 5. ARL's tower array and sonic anemometer positions.

The outputs of all sonic anemometers were continuously downloaded using PC computers/ laptops and stored in ASCII data file format. Recorded Universal Time Coordinated (UTC) time on PC computers/laptops was set to maintain synchronization of all sonic anemometers.

Each data collection period was designated as an IOP and lasted from early evening until the next morning. Since the experiment focused on clear sky, calm wind, and nocturnal boundary layer (NBL) conditions, IOPs were carried out only on those days when the weather forecast seemed promising. The ARL team started its data collection on 9 October and ended on 21 October 1999 for a total of seven IOPs (table 1).

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Table 1. A list of the IOPs during which the ARL sonic anemometers have collected data (in UTC time).

IOP	Start Time	Date	End Tme	Date	Observed Events
3	2200	10/09	1300	10/10	W Jet at 10 m/s, 60–120 m AGL.
4	2200	10/10	1300	10/11	Post-frontal ENE Jet at 17 m/s, 100–200 m AGL.
5	2200	10/11	1300	10/12	Weak surface flow with strong flow aloft to 17 m/s near 250 m AGL; K-H and wave-like structures observed.
6	2200	10/13	1300	10/14	NE-E jet at 9–12 m/s,120–180 m AGL; Turbulence/wave sheets; Turbulent busting gravity waves; K-H activity; LLJ dissipation.
7	2200	10/17	1300	10/18	Surface-based turbulence; N->E->SE jet at 10 m/s, 200–300 m ->100 m AGL.
8	2200	10/19	1300	10/20	S-SW jet at 11 m/s, 60–120 m AGL; Little wave activity.
9	2200	10/20	1300	10/21	S-SW jet at 10–12 m/s,100–200 m AGL; A fossil turbulence event and nearly continuous, weak surface-based turbulence.

2.3 Description of the ARL Sonic Anemometer/Thermometer

The sonic anemometer/thermometer used by ARL for the CASES-99 is the three-axis sonic wind system (anemometer/thermometer) developed by the Applied Technologies Inc. (1988). Figure 6 illustrates the sonic anemometer-thermometer probe array.

Kaimal and Finnigan (1994) have provided an excellent description on the working principles and measurements of sonic anemometers. An operator's manual for the SWS-211/3K system (Applied Technologies Inc. 1988) also provides working knowledge and operation instructions for this instrument.

The equations for the calculation of wind speed (S) along the three axes and of temperature (T, actually virtual temperature, T_v) are:

$$S = (d/2)\,(1/t_1 - 1/t_2)\,, \tag{1}$$

$$T_v = (1 + 0.379\,e/p)T = (M/\gamma R)\,c^2 = c^2/\,401.9\,, \tag{2}$$

where d is the distance (15 cm) between the two transducers in the same axis; t_1 and t_2 are the transit times of an acoustic signal along the two opposite directions of the axis; e and p are water vapor pressure and air pressure, respectively; M is the molecular weight of the air (28.97); R is the universal gas constant (8314.3); $\gamma = C_p/C_v = 1.4$, the ratio of the specific heat at constant pressure and at constant volume; and c is the speed of sound that can be approximated by
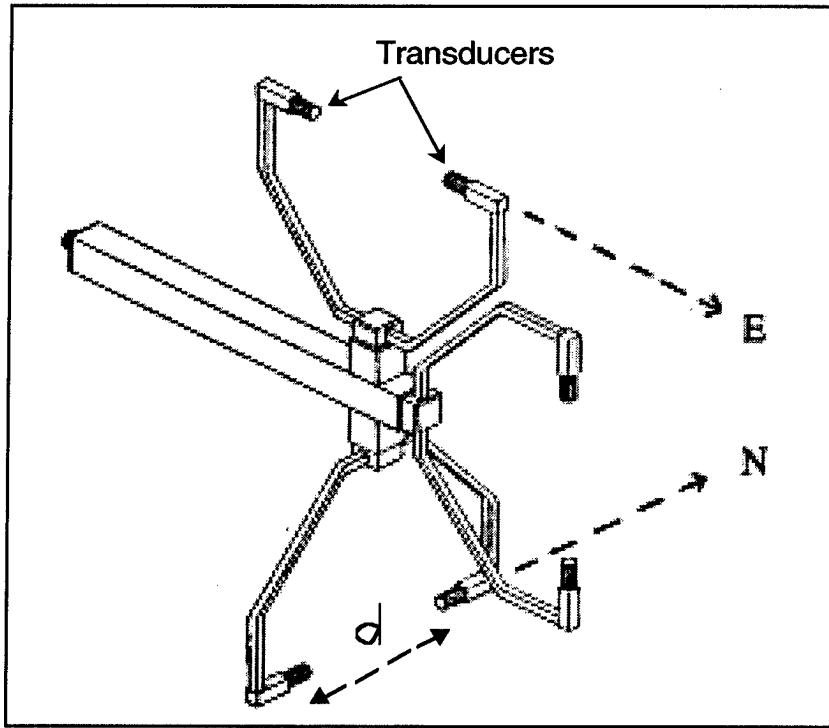
Figure 6. Applied Technologies single-path (d = 0.15m) orthogonal sonic anemometer-thermometer probe.

$$c = (d/2)\,(1/t_1 + 1/t_2)\,. \tag{3}$$

The instrument uses a microcomputer-based digital electronic measurement system to measure t_1 and t_2. Therefore, S and T_v can be calculated when d is known. The sonic path length (d) of this system is 0.15 m for all three axes. It needs, however, to be calibrated during a field experiment. Using a "zero-air chamber" in which $S = 0$ and $t_1 = t_2$ from equation (1), d can be derived from equation (3):

$$d = c\,t_1 = c\,t_2\,, \tag{4}$$

and the speed of acoustic waves (c) can be calculated from equation (2) once the temperature of the chamber is measured. The sampling rate of the SWS-211/3K system is 10 Hz. The system can measure within the range of ±20 m/s for horizontal wind, ±5 m/s for vertical wind, and from $-20°$ to $+50$ °C for temperature.

In the orthogonal array of figure 6, partial shadowing of the acoustic path by the transducers (1 cm in diameter) causes the speed-readings (S_m, measured speed) to be underestimated, as discussed by Wyngaard and Zhang (1984). A correction for this flow distortion effect has been built in the software of the system (Zimmerman 2000). The corrected speed (S_c) is calculated by the following equations:

$$S_c = S_m \qquad\qquad \text{for } \phi > 70°\,, \tag{5a}$$

$$S_c = S_m/[0.84 + 0.16\,(\phi/70)] \qquad \text{for } \phi \le 70°\,, \tag{5b}$$

where ϕ (in degree) is the angle between the wind direction and the acoustic path.

2.4 Data Processing and Computation

The output data from the three-axis sonic anemometer/thermometer consist of four time series of three wind speed components, S_c of equation (5), along three axes (known as u, v, w) and of virtual temperature, T_v of equation (2).

The data processing and computation of those four time series includes three aspects as described in the following three subsections.

2.4.1 Spike Detection and Removal

A spike in a time series refers to a sudden big change (jump or drop) in the time series of output signals. It does not reflect any meaningful change of the measured quantity (meteorological variable). Therefore, spikes bring errors for measurements and should be removed by a "despiking" scheme as the first step in data processing. For this field experiment, spikes can occur under various situations. First, it could be the mechanical failure of the sonic anemometer being used, as in the case of the sonic anemometer at 5 m AGL on tower T5. In this case, the spikes occur periodically and in a similar pattern. Second, since the field experiment was carried out on an open grassy field and since the sonic anemometers were placed a few meters above the ground, insects were flying across the acoustic path or landing on one of the transducers and the acoustic signals were disrupted as a result. Third, an irregular electrical surge from the power supply/batteries could also interfere with the sonic anemometer output signals. Fourth, moisture and dust could damage briefly the sonic anemometer or its controlling computer. Fifth, cows tripping disturbed (even tore apart) cables connected between the sonic anemometer's electronic box and the controlling computers. Last, errors could be introduced during downloading process to save data into files due to programming errors. Generally, spikes can be identified through visual inspection of the time series. The mathematical definition of a spike, however, is more or less subjective. Usually, a jump or drop in a time series, which is significantly greater than the standard deviation, can be defined as a spike. Consequently, the criteria to detect spikes vary. Oncley (1989), for example, used a jump of 3 m/s in the wind speed to define a spike, and it was replaced by previous value of speed in his despiking scheme. For the ARL sonic anemometer/thermometer, the following criteria are adopted:

$$\Delta T > 3 \text{ °C or } \Delta S > 3 \text{ m/s},$$

where Δ means the change between two adjacent data points. After all spikes have been labeled and removed, the value of the variable is then replaced by the average of the points ahead of and behind the spike. For a data set (usually 30 min of data), if the total number of spikes is more than 5 percent of the total data points, the data set is considered useless. During the preliminary processing, it was discovered that there were too many spikes in the data sets from both sonic anemometers (2 and 5 m AGL) on tower T5. Therefore, the data collected on tower T5 are excluded from the present study.

2.4.2 Coordinate Systems

There are three kinds of orthogonal coordinate systems relating to sonic anemometer data: sonic anemometer coordinates, conventional meteorological coordinates, and local mean streamline coordinates. The three orthogonal axes of the sonic anemometer are referred to as sonic anemometer coordinates. During the field experiment, these three axes were aligned to the east, north, and vertical directions as indicated in figure 6. The outputs of the corrected speed from equation

(5) along the three axes are denoted as (u_1, v_1, w_1), where positive u_1 is in the E-W direction, positive v_1 is in the N-S direction, and positive w_1 is in the vertical upward direction. Although all instruments were carefully aligned and leveled with those local directions, they still might not guarantee absolute accuracies because a strong wind could shake or twist the tower platform or the anemometer probes from its corrected position. For example, the 1-min mean vertical wind speed from the 5-m AGL anemometer on tower T3 has shown an average value of 0.033 m/s for the entire 16 hr of IOP9. This may imply that the vertical axis of the anemometer could not be strictly in the vertical (90°) position (Wilczak et al. 2001).

For the conventional meteorological coordinates (x,y,z), the three wind components u_2, v_2, w_2 along x, y, and z are defined in such a way that u_2 is in the x (W-E) direction, v_2 is in the y (S-N) direction, and w_2 is in vertical upward direction. Therefore, the relation between these two coordinates is:

$$u_2 = -u_1$$
$$v_2 = -v_1 \tag{6}$$
$$w_2 = w_1 \; .$$

As a convention in meteorology, the wind speed (S) and wind direction (θ) are defined, respectively, as:

$$S = \left[u_2{}^2 + v_2{}^2\right]^{1/2} \; ; \tag{7}$$

$$\psi = 270° - \text{atan2}(v_2, u_2) \times 180/\pi \; . \tag{8}$$

The local mean streamline coordinate system (mean wind vector coordinates) has been discussed by Kaimal and Finnigan (1994). The three wind components in this coordinate system (u_3, v_3, w_3) can be calculated from (u_2, v_2, w_2) by the following transformation:

$$\begin{vmatrix} u_3 \\ v_3 \\ w_3 \end{vmatrix} = \begin{vmatrix} \cos\delta \; \cos\lambda & \cos\delta \; \sin\lambda & \sin\delta \\ -\sin\lambda & \cos\lambda & 0 \\ -\sin\lambda \; \cos\lambda & -\sin\delta \; \sin\lambda & \cos\delta \end{vmatrix} \begin{vmatrix} u_2 \\ v_2 \\ w_2 \end{vmatrix} . \tag{9}$$

where

$$\lambda = \tan^{-1}\left(\overline{v}_2/\overline{u}_2\right) \; , \tag{10}$$

$$\delta = \tan^{-1}\left[\overline{w}_2/\left(\overline{u}_2{}^2 + \overline{v}_2{}^2\right)^{1/2}\right] \; , \tag{11}$$

where the overbar means the average values. In the local mean streamline coordinate,

$$\overline{v}_3 = \overline{w}_3 = 0 . \tag{12}$$

For the derivations of equations (9–12), see Kaimal and Finnigan (1994).

2.4.3 Computation of Turbulence Quantities

After the coordinate transformation into the mean wind coordinates, the instantaneous wind speed components, (u_3, v_3, w_3), and the temperature (T) can be separated into a mean component and a turbulence (eddy) component such as:

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$$u_3 = \bar{u}_3 + u_3{'}$$
$$v_3 = \bar{v}_3 + v_3{'}$$
$$w_3 = \bar{w}_3 + w_3{'} \tag{13}$$
$$T = \bar{T} + T{'} \; .$$

A 30-min averaging time has been adopted to calculate the mean values. By definition, mean values of all turbulence components as well as of v_3, w_3 wind component should approach zero $\left(\bar{u}_3{'} = \bar{v}_3{'} = \bar{w}_3{'} = \bar{T}{'} = \bar{v}_3 = \bar{w}_3 = 0\right)$.

The following turbulence quantities have been computed:

$$\tau = \rho\, u_*{}^2 = \rho\left[\left(\overline{u_3{'}w_3{'}}\right)^2 + \left(\overline{v_3{'}w_3{'}}\right)^2\right]^{1/2} \; ; \tag{14}$$

$$H = \overline{w_3{'}T{'}} \; ; \tag{15}$$

$$\sigma_u = \left(\overline{u_3{'}^2}\right)^{1/2} \; ; \tag{16}$$

$$\sigma_v = \left(\overline{v_3{'}^2}\right)^{1/2} \; ; \tag{17}$$

$$\sigma_w = \left(\overline{w_3{'}^2}\right)^{1/2} \; ; \tag{18}$$

$$\sigma_T = \left(\overline{T{'}^2}\right)^{1/2} \; ; \tag{19}$$

where u_* is the friction velocity, H is the kinematic heat flux, and τ is the Reynolds stress (momentum flux). The other turbulence statistics are defined as usual.

$$T_* = -H/u_* \; ; \tag{20}$$
$$L = -u_*{}^3/k\left(g/\bar{T}\right)H \; . \tag{21}$$

The computational results of some of these turbulence statistics along with mean quantities will be presented in the next section.

3. Computational Results and Preliminary Analyses

The results of the previous computation have been used first for an intercomparison between the measurements at 2- and 5-m levels from the same tower (T3), then between the measurements at the 2-m level from the four different towers (T1, T2, T3, and T4).

3.1 Intercomparison of the Measurements at 2- and 5-m Levels from the Same Tower (T3)

The two corresponding data files from the 2- and 5-m level measurements have been trimmed to have the same starting time and ending time for each IOP, which has been listed in table 1. Tables 2(a and b) through 8(a and b) list the computed numerical values for both mean quantities and turbulence statistics for each IOP, respectively.

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Table 2. Mean values and turbulence statistics from two sonic anemometers at 5 and 2 m AGL on tower T3 for IOP3 (9–10 October 1999).

a. Mean values.

Time(CDT)	u (m/s) 5m	u (m/s) 2m	v (m/s) 5m	v (m/s) 2m	w (m/s) 5m	w (m/s) 2m	Spd (m/s) 5m	Spd (m/s) 2m	Wdir(deg) 5m	Wdir(deg) 2m	T (C) 5m	T (C) 2m
1700-1730	-1.80	-0.95	0.18	0.21	-0.09	-0.06	1.83	1.00	274.86	282.37	23.33	26.64
1730-1800	-0.94	-0.37	-0.21	-0.04	-0.06	-0.04	0.99	0.42	256.09	261.36	22.46	25.44
1800-1830	-0.54	-0.02	-0.42	-0.17	-0.04	-0.03	0.72	0.31	230.00	214.86	21.43	24.05
1830-1900	0.65	0.95	-0.65	-0.05	0.00	-0.03	0.98	0.99	138.87	90.79	20.41	22.36
1900-1930	0.64	1.03	-1.19	-0.34	0.06	0.01	1.39	1.09	150.85	107.99	20.23	22.23
1930-2000	0.52	1.08	-1.67	-0.51	0.07	0.03	1.77	1.21	162.69	114.47	19.25	20.77
2000-2030	-0.06	0.40	-1.23	-0.39	0.02	0.00	1.30	0.66	183.51	137.70	18.08	20.19
2030-2100	-0.72	-0.19	-0.96	-0.28	-0.03	-0.02	1.22	0.37	217.03	215.91	17.68	20.13
2100-2130	-0.55	0.12	-1.48	-0.87	0.00	0.03	1.61	1.00	200.85	173.31	17.24	19.64
2130-2200	-0.32	0.30	-1.12	-0.51	-0.01	0.01	1.21	0.73	196.49	153.65	16.85	19.39
2200-2230	0.06	0.94	-1.41	-0.50	0.02	0.01	1.45	1.16	177.56	120.07	16.57	18.53
2230-2300	0.33	0.80	-1.43	-0.39	0.04	-0.01	1.53	0.92	169.43	119.36	15.61	17.31
2300-2330	-0.98	-0.39	-0.80	-0.34	-0.06	-0.02	1.31	0.58	232.31	232.47	15.67	18.38
2330-2400	-0.67	-0.04	-1.11	-0.56	-0.02	0.01	1.33	0.59	211.75	190.55	15.41	17.95
0000-0030	-0.53	-0.01	-1.11	-0.50	-0.01	0.01	1.26	0.60	206.73	201.41	15.48	18.10
0030-0100	-0.77	-0.21	-1.07	-0.45	-0.03	-0.02	1.32	0.50	216.10	205.58	15.14	17.67
0100-0130	-0.66	-0.15	-1.04	-0.39	-0.03	-0.03	1.23	0.44	212.49	202.10	14.75	17.31
0130-0200	-0.38	0.28	-1.34	-0.78	0.01	0.02	1.41	0.86	196.02	162.12	14.66	17.05
0200-0230	-0.10	0.68	-1.43	-0.69	0.01	0.01	1.50	1.11	185.20	142.04	14.68	16.74
0230-0300	-0.18	0.43	-0.86	-0.29	-0.01	-0.02	0.90	0.55	194.28	121.59	14.47	16.81
Average:	-0.35	0.23	-1.02	-0.39	-0.01	-0.01	1.31	0.75	200.66	172.48	17.47	19.83

b. Turbulence statistics.

Time(CDT)	ustar(m/s) 5m	ustar(m/s) 2m	w'T'(Km/s) 5m	w'T'(Km/s) 2m	u'u' 5m	u'u' 2m	v'v' 5m	v'v' 2m	w'w' 5m	w'w' 2m	T'T' 5m	T'T' 2m
1700-1730	0.15	0.09	-0.01	0.00	0.38	0.25	0.07	0.04	0.03	0.02	0.14	0.20
1730-1800	0.08	0.05	0.00	0.00	0.07	0.03	0.05	0.04	0.01	0.00	0.07	0.17
1800-1830	0.03	0.12	0.00	0.00	0.02	0.04	0.04	0.05	0.00	0.00	0.13	0.08
1830-1900	0.03	0.08	0.00	0.02	0.08	0.12	0.10	0.05	0.00	0.00	0.24	0.83
1900-1930	0.05	0.02	0.00	0.00	0.02	0.01	0.11	0.03	0.00	0.00	0.22	0.20
1930-2000	0.07	0.02	-0.02	0.00	0.02	0.03	0.05	0.04	0.00	0.00	0.43	0.66
2000-2030	0.10	0.06	0.00	0.00	0.03	0.04	0.20	0.14	0.00	0.00	0.10	0.29
2030-2100	0.04	0.05	0.00	0.00	0.01	0.01	0.03	0.02	0.00	0.00	0.03	0.03
2100-2130	0.09	0.04	-0.01	0.00	0.10	0.06	0.09	0.22	0.01	0.00	0.06	0.29
2130-2200	0.07	0.05	0.00	0.00	0.03	0.03	0.12	0.20	0.00	0.00	0.03	0.12
2200-2230	0.06	0.09	-0.01	0.01	0.04	0.08	0.12	0.17	0.01	0.01	0.08	0.38
2230-2300	0.07	0.09	0.00	0.00	0.10	0.21	0.17	0.04	0.01	0.01	0.13	0.25
2300-2330	0.09	0.08	0.00	-0.01	0.09	0.07	0.10	0.07	0.02	0.01	0.09	0.06
2330-2400	0.07	0.07	0.00	0.01	0.03	0.06	0.07	0.04	0.01	0.01	0.05	0.12
0000-0030	0.08	0.11	0.00	0.01	0.02	0.11	0.08	0.08	0.01	0.00	0.03	0.12
0030-0100	0.04	0.05	0.00	0.00	0.03	0.03	0.02	0.01	0.00	0.00	0.02	0.06
0100-0130	0.03	0.05	0.00	0.00	0.02	0.01	0.01	0.02	0.00	0.00	0.02	0.03
0130-0200	0.05	0.05	0.00	0.00	0.03	0.04	0.03	0.05	0.00	0.01	0.02	0.10
0200-0230	0.09	0.06	0.00	0.01	0.03	0.12	0.18	0.23	0.00	0.01	0.03	0.46
0230-0300	0.08	0.06	0.00	0.02	0.05	0.02	0.05	0.04	0.00	0.01	0.05	0.34
Average:	0.07	0.07	0.00	0.00	0.06	0.07	0.08	0.08	0.01	0.01	0.10	0.24

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Table 3. Mean values and turbulence statistics from two sonic anemometers at 5 and 2 m AGL on tower T3 for IOP4 (10–11 October 1999).

a. Mean values.

Time(CDT)	u (m/s) 5m	u (m/s) 2m	v (m/s) 5m	v (m/s) 2m	w (m/s) 5m	w (m/s) 2m	Spd(m/s) 5m	Spd(m/s) 2m	Wdir(deg) 5m	Wdir(deg) 2m	T (C) 5m	T (C) 2m
1830-1900	-0.76	-0.06	0.92	1.17	-0.10	-0.06	1.29	1.19	317.03	329.95	23.45	25.03
1900-1930	-0.43	-0.04	1.55	1.35	-0.12	-0.14	1.62	1.36	344.18	346.24	23.51	24.93
1930-2000	0.30	0.30	2.26	1.56	-0.12	-0.13	2.40	1.67	162.56	177.91	21.59	22.55
2000-2030	1.06	0.86	3.26	2.43	-0.15	-0.11	3.49	2.63	46.96	72.47	19.08	21.73
2030-2100	1.39	1.08	2.80	2.10	-0.14	-0.09	3.15	2.39	26.41	31.81	18.05	20.73
2100-2130	1.45	1.15	2.63	1.91	-0.14	-0.10	3.01	2.25	28.97	31.65	16.94	19.58
2130-2200	1.65	1.25	2.24	1.61	-0.12	-0.07	2.80	2.06	36.51	37.89	16.06	18.68
2200-2230	1.69	1.21	1.28	0.84	-0.07	-0.05	2.19	1.53	54.41	57.51	15.04	17.49
2230-2300	1.99	1.31	1.32	1.02	-0.07	-0.05	2.41	1.69	57.18	52.60	14.77	17.10
2300-2330	2.12	1.51	1.73	1.31	-0.08	-0.05	2.75	2.02	50.71	49.23	15.05	17.68
2330-2400	2.19	1.56	1.53	1.20	-0.08	-0.05	2.68	1.99	55.02	52.52	15.17	17.82
0000-0030	2.31	1.75	1.92	1.62	-0.09	-0.07	3.03	2.42	50.21	47.14	15.41	18.20
0030-0100	2.86	2.29	2.11	1.82	-0.07	-0.08	3.59	2.97	53.24	51.21	15.58	18.49
0100-0130	4.00	3.20	1.97	1.72	-0.05	-0.06	4.50	3.68	63.51	61.46	15.85	18.81
0130-0200	4.21	3.37	2.15	1.89	-0.07	-0.08	4.77	3.91	62.87	60.48	15.63	18.59
0200-0230	4.00	3.23	1.85	1.60	-0.06	-0.04	4.45	3.65	65.03	63.36	15.18	18.14
0230-0300	4.49	3.62	1.85	1.65	-0.04	-0.05	4.90	4.04	67.52	65.28	15.13	18.10
0300-0330	4.11	3.35	1.93	1.62	-0.04	-0.05	4.59	3.78	64.82	63.91	14.61	17.56
0330-0400	4.30	3.55	1.49	1.30	-0.04	-0.04	4.60	3.83	70.85	69.66	14.29	17.25
0400-0430	4.44	3.62	1.36	1.29	-0.01	-0.03	4.69	3.90	73.18	70.45	14.06	17.00
Average:	2.37	1.91	1.91	1.55	-0.08	-0.07	3.35	2.65	87.56	89.64	16.72	19.27

b. Turbulence statistics.

Time(CDT)	ustar(m/s) 5m	ustar(m/s) 2m	w'T'(Km/s) 5m	w'T'(Km/s) 2m	u'u' 5m	u'u' 2m	v'v' 5m	v'v' 2m	w'w' 5m	w'w' 2m	T'T' 5m	T'T' 2m
1830-1900	0.04	0.07	0.00	0.00	0.05	0.05	0.24	0.03	0.00	0.00	0.09	0.35
1900-1930	0.04	0.02	0.00	-0.01	0.03	0.02	0.03	0.02	0.00	0.01	0.04	0.17
1930-2000	0.15	0.08	-0.02	-0.04	0.50	0.26	0.61	0.32	0.01	0.02	2.39	1.65
2000-2030	0.21	0.21	-0.04	-0.04	0.35	0.32	0.37	0.27	0.08	0.08	0.16	0.16
2030-2100	0.18	0.19	-0.03	-0.03	0.15	0.17	0.15	0.13	0.06	0.06	0.12	0.12
2100-2130	0.17	0.17	-0.02	-0.03	0.13	0.15	0.08	0.09	0.05	0.05	0.20	0.21
2130-2200	0.16	0.16	-0.03	-0.03	0.13	0.13	0.10	0.10	0.05	0.05	0.11	0.10
2200-2230	0.14	0.11	-0.02	-0.04	0.14	0.13	0.29	0.16	0.02	0.05	0.27	0.49
2230-2300	0.10	0.10	-0.01	-0.03	0.12	0.11	0.10	0.08	0.02	0.04	0.14	0.23
2300-2330	0.17	0.17	-0.03	-0.03	0.14	0.15	0.09	0.09	0.05	0.05	0.08	0.09
2330-2400	0.17	0.17	-0.02	-0.03	0.15	0.16	0.10	0.09	0.05	0.05	0.20	0.26
0000-0030	0.20	0.23	-0.03	-0.04	0.28	0.26	0.13	0.14	0.08	0.08	0.08	0.09
0030-0100	0.27	0.28	-0.04	-0.04	0.46	0.49	0.28	0.29	0.13	0.12	0.08	0.10
0100-0130	0.36	0.35	-0.05	-0.04	0.73	0.71	0.38	0.36	0.22	0.18	0.07	0.07
0130-0200	0.38	0.40	-0.05	-0.05	0.76	0.83	0.41	0.40	0.22	0.20	0.07	0.08
0200-0230	0.37	0.36	-0.04	-0.04	0.66	0.69	0.36	0.38	0.21	0.18	0.05	0.05
0230-0300	0.40	0.38	-0.04	-0.04	0.80	0.87	0.43	0.46	0.25	0.22	0.04	0.05
0300-0330	0.40	0.37	-0.04	-0.04	0.86	0.86	0.43	0.42	0.23	0.21	0.08	0.08
0330-0400	0.39	0.38	-0.04	-0.04	0.85	0.89	0.41	0.41	0.23	0.21	0.04	0.04
0400-0430	0.44	0.43	-0.04	-0.04	0.94	1.02	0.44	0.44	0.25	0.21	0.04	0.05
Average:	0.24	0.23	-0.03	-0.03	0.41	0.41	0.27	0.23	0.11	0.10	0.22	0.22

Table 4. Mean values and turbulence statistics from two sonic anemometers at 5 and 2 m AGL on tower T3 for IOP5 (11–12 October 1999).

a. Mean values.

Time(CDT)	u (m/s) 5m	u (m/s) 2m	v (m/s) 5m	v (m/s) 2m	w (m/s) 5m	w (m/s) 2m	Spd(m/s) 5m	Spd(m/s) 2m	Wdir (deg) 5m	Wdir (deg) 2m	T (C) 5m	T (C) 2m
1700-1730	0.59	0.79	-2.60	-1.81	0.08	0.16	2.69	2.00	167.26	156.11	24.71	27.84
1730-1800	0.84	0.92	-1.94	-1.04	0.04	0.10	2.14	1.42	156.22	138.35	23.15	25.44
1800-1830	1.06	0.96	-1.71	-0.89	0.04	0.08	2.02	1.32	148.05	132.48	21.15	23.24
1830-1900	1.07	1.01	-1.30	-0.47	0.02	0.06	1.69	1.12	140.21	114.87	19.73	22.09
1900-1930	0.23	0.17	-1.82	-1.13	0.03	0.09	1.94	1.25	175.31	173.89	18.79	21.24
1930-2000	0.58	0.67	-2.02	-1.12	0.04	0.09	2.16	1.34	163.79	149.07	17.98	20.17
2000-2030	1.04	1.07	-1.67	-0.68	0.04	0.07	2.01	1.36	146.55	123.06	17.44	19.52
2030-2100	1.46	1.34	-1.77	-0.84	0.03	0.07	2.31	1.60	140.01	121.74	16.79	18.80
2100-2130	1.34	1.13	-2.33	-1.37	0.06	0.11	2.70	1.79	149.92	140.23	16.74	19.16
2130-2200	1.30	1.12	-2.63	-1.67	0.08	0.13	2.95	2.04	153.39	145.89	17.02	19.61
2200-2230	1.34	1.21	-2.94	-2.02	0.08	0.16	3.25	2.38	155.45	149.13	17.45	20.20
2230-2300	1.46	1.36	-2.70	-1.82	0.07	0.14	3.09	2.31	151.46	143.17	17.42	20.19
2300-2330	1.26	1.11	-2.67	-1.84	0.08	0.14	2.98	2.18	154.77	148.89	17.31	20.04
2330-2400	0.86	0.81	-3.03	-2.12	0.08	0.16	3.17	2.29	164.14	158.98	17.24	19.99
0000-0030	0.75	0.81	-3.21	-2.14	0.08	0.16	3.31	2.31	166.83	159.14	17.07	19.72
0030-0100	0.61	0.69	-3.22	-2.26	0.09	0.17	3.30	2.39	169.24	162.69	17.11	19.85
0100-0130	0.24	0.36	-3.34	-2.38	0.11	0.18	3.37	2.44	176.01	171.32	17.39	20.17
0130-0200	-0.09	0.15	-3.64	-2.66	0.10	0.18	3.66	2.69	181.49	176.60	17.57	20.39
0200-0230	0.01	0.25	-4.04	-3.01	0.11	0.19	4.07	3.06	179.98	175.27	17.90	20.74
0230-0300	-0.06	0.16	-3.34	-2.36	0.10	0.17	3.36	2.40	181.09	175.99	17.54	20.29
0300-0330	-0.38	-0.13	-2.98	-2.09	0.06	0.14	3.03	2.12	187.52	183.59	17.06	19.80
0330-0400	-0.42	-0.15	-3.42	-2.60	0.08	0.17	3.47	2.63	186.85	183.10	16.74	19.60
0400-0430	-0.63	-0.29	-3.44	-2.54	0.06	0.15	3.52	2.60	190.39	186.27	16.55	19.41
0430-0500	-0.62	-0.26	-3.48	-2.56	0.08	0.17	3.56	2.61	190.11	185.62	16.43	19.29
0500-0530	-0.36	-0.01	-3.30	-2.45	0.08	0.15	3.35	2.48	186.13	179.96	16.20	19.04
0530-0600	-0.22	0.16	-3.33	-2.47	0.09	0.17	3.37	2.51	183.93	176.40	15.71	18.50
Average:	0.51	0.59	-2.76	-1.86	0.07	0.14	2.94	2.10	167.16	158.15	17.93	20.55

b. Turbulence statistics.

Time(CDT)	ustar(m/s) 5m	ustar(m/s) 2m	w'T'(Km/s) 5m	w'T'(Km/s) 2m	u'u' 5m	u'u' 2m	v'v' 5m	v'v' 2m	w'w' 5m	w'w' 2m	T'T' 5m	T'T' 2m
1700-1730	0.20	0.19	-0.01	-0.01	0.31	0.26	0.11	0.11	0.06	0.05	0.17	0.30
1730-1800	0.07	0.06	0.00	0.00	0.04	0.03	0.13	0.10	0.01	0.01	0.35	0.67
1800-1830	0.05	0.06	-0.01	-0.01	0.09	0.04	0.03	0.04	0.01	0.01	0.31	0.39
1830-1900	0.05	0.04	0.00	0.00	0.06	0.02	0.02	0.02	0.01	0.00	0.14	0.09
1900-1930	0.10	0.06	0.00	-0.01	0.22	0.09	0.37	0.25	0.01	0.01	0.19	0.21
1930-2000	0.05	0.06	0.00	0.00	0.07	0.03	0.22	0.09	0.01	0.01	0.20	0.20
2000-2030	0.06	0.11	0.00	0.00	0.10	0.02	0.18	0.23	0.01	0.01	0.14	0.15
2030-2100	0.03	0.06	-0.01	-0.01	0.09	0.03	0.05	0.07	0.01	0.01	0.06	0.10
2100-2130	0.12	0.12	-0.02	-0.02	0.10	0.09	0.06	0.06	0.03	0.03	0.11	0.14
2130-2200	0.15	0.16	-0.02	-0.03	0.16	0.14	0.11	0.11	0.04	0.04	0.10	0.12
2200-2230	0.19	0.19	-0.03	-0.03	0.18	0.17	0.11	0.12	0.06	0.06	0.10	0.10
2230-2300	0.19	0.20	-0.03	-0.03	0.21	0.21	0.15	0.15	0.07	0.06	0.10	0.10
2300-2330	0.18	0.16	-0.03	-0.03	0.20	0.17	0.18	0.15	0.06	0.05	0.10	0.10
2330-2400	0.18	0.18	-0.03	-0.03	0.19	0.18	0.10	0.10	0.06	0.05	0.07	0.10
0000-0030	0.18	0.18	-0.03	-0.03	0.17	0.18	0.09	0.09	0.06	0.05	0.09	0.10
0030-0100	0.22	0.19	-0.04	-0.03	0.24	0.22	0.12	0.13	0.07	0.06	0.11	0.14
0100-0130	0.21	0.21	-0.03	-0.03	0.34	0.31	0.18	0.17	0.09	0.07	0.12	0.13
0130-0200	0.20	0.23	-0.04	-0.04	0.32	0.36	0.15	0.16	0.09	0.08	0.12	0.16
0200-0230	0.24	0.24	-0.04	-0.04	0.41	0.44	0.24	0.23	0.13	0.10	0.08	0.10
0230-0300	0.20	0.21	-0.03	-0.03	0.35	0.31	0.15	0.13	0.08	0.06	0.12	0.14
0300-0330	0.18	0.17	-0.03	-0.03	0.24	0.22	0.13	0.12	0.07	0.05	0.10	0.13
0330-0400	0.21	0.23	-0.03	-0.03	0.37	0.39	0.16	0.16	0.09	0.08	0.08	0.09
0400-0430	0.23	0.23	-0.03	-0.03	0.35	0.34	0.18	0.19	0.09	0.08	0.07	0.08
0430-0500	0.23	0.22	-0.03	-0.03	0.36	0.32	0.18	0.19	0.10	0.08	0.07	0.09
0500-0530	0.20	0.20	-0.03	-0.03	0.31	0.31	0.20	0.19	0.09	0.07	0.11	0.13
0530-0600	0.19	0.21	-0.04	-0.03	0.31	0.33	0.19	0.17	0.09	0.07	0.11	0.11
Average:	0.16	0.16	-0.02	-0.02	0.22	0.20	0.15	0.14	0.06	0.05	0.13	0.16

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Table 5. Mean values and turbulence statistics from two sonic anemometers at 5 and 2 m AGL on tower T3 for IOP8 (19–20 October 1999).

a. Mean values.

Time(CDT)	u (m/s) 5m	u (m/s) 2m	v (m/s) 5m	v (m/s) 2m	w (m/s) 5m	w (m/s) 2m	Spd (m/s) 5m	Spd (m/s) 2m	Wdir (deg) 5m	Wdir (deg) 2m	T (C) 5m	T (C) 2m
1700-1730	1.50	1.26	2.72	2.21	-0.12	-0.09	3.14	2.59	29.62	32.02	17.48	20.47
1730-1800	1.22	0.94	2.11	1.47	-0.14	-0.09	2.45	1.76	29.86	32.66	15.84	18.06
1800-1830	1.51	0.99	2.09	1.36	-0.12	-0.07	2.58	1.69	36.04	36.03	14.45	15.96
1830-1900	1.77	1.09	1.74	1.23	-0.10	-0.06	2.48	1.66	45.58	41.91	13.15	14.45
1900-1930	1.63	0.99	1.51	1.11	-0.10	-0.05	2.22	1.50	47.17	41.76	11.88	13.61
1930-2000	1.64	1.03	1.79	1.34	-0.12	-0.06	2.43	1.70	42.58	37.54	11.01	12.93
2000-2030	1.65	1.01	1.94	1.45	-0.12	-0.07	2.55	1.78	40.18	34.96	10.28	12.36
2030-2100	1.76	1.13	1.93	1.42	-0.13	-0.07	2.62	1.83	42.61	38.72	9.71	11.92
2100-2130	1.74	1.13	1.78	1.35	-0.10	-0.06	2.50	1.78	44.45	39.87	9.16	11.34
2130-2200	1.94	1.32	1.69	1.35	-0.09	-0.06	2.59	1.90	49.06	44.38	8.88	11.23
2200-2230	2.10	1.45	1.51	1.20	-0.08	-0.05	2.61	1.91	54.35	50.38	8.86	11.28
2230-2300	1.86	1.19	1.02	0.70	-0.06	-0.03	2.14	1.41	62.08	61.42	8.20	10.39
2300-2330	1.05	0.67	-0.01	0.11	-0.02	0.00	1.07	0.69	91.85	81.11	7.37	9.47
2330-2400	1.45	0.97	0.39	0.61	-0.04	-0.03	1.51	1.17	75.99	58.60	8.12	9.68
0000-0030	1.92	1.04	0.98	0.80	-0.06	-0.04	2.17	1.33	63.04	52.50	7.77	8.99
0030-0100	2.01	1.07	0.66	0.62	-0.04	-0.04	2.13	1.25	72.28	59.84	6.97	8.18
0100-0130	1.87	0.95	0.61	0.62	-0.03	-0.03	1.97	1.14	72.05	56.89	7.69	8.79
0130-0200	1.45	0.77	0.26	0.51	-0.03	-0.03	1.48	0.94	80.01	57.55	7.75	9.06
0200-0230	1.63	0.82	0.69	0.72	-0.04	-0.04	1.78	1.10	67.31	48.33	8.35	9.55
0230-0300	0.34	-0.04	0.27	0.15	-0.04	-0.01	0.80	0.51	167.11	189.42	6.99	8.44
0300-0330	1.06	0.74	0.50	0.81	-0.05	-0.04	1.18	1.11	62.49	40.48	7.61	9.09
0330-0400	1.68	0.80	0.89	0.82	-0.05	-0.05	1.91	1.15	62.29	44.54	7.24	8.27
0400-0430	1.61	0.78	0.82	0.79	-0.04	-0.05	1.82	1.12	62.83	44.52	6.96	8.27
0430-0500	1.54	0.81	1.23	1.01	-0.07	-0.06	1.98	1.30	51.48	39.00	6.27	7.96
0500-0530	1.08	0.51	1.25	0.85	-0.07	-0.05	1.67	1.04	39.00	82.57	5.40	7.45
0530-0600	0.23	-0.02	1.15	0.90	-0.08	-0.07	1.21	0.94	170.68	199.29	5.13	6.65
0600-0630	0.89	0.44	1.54	1.12	-0.09	-0.08	1.79	1.23	29.26	57.13	5.54	7.10
Average:	1.49	0.88	1.22	0.99	-0.07	-0.05	2.03	1.39	62.64	59.39	9.04	10.78

b. Turbulence statistics.

Time(CDT)	ustar(m/s) 5m	ustar(m/s) 2m	w'T'(Km/s) 5m	w'T'(Km/s) 2m	u'u' 5m	u'u' 2m	v'v' 5m	v'v' 2m	w'w' 5m	w'w' 2m	T'T' 5m	T'T' 2m
1700-1730	0.25	0.25	-0.01	-0.01	0.40	0.36	0.27	0.24	0.10	0.08	0.18	0.30
1730-1800	0.11	0.10	-0.01	-0.01	0.09	0.11	0.05	0.05	0.02	0.03	0.29	0.82
1800-1830	0.05	0.08	-0.01	-0.01	0.05	0.05	0.02	0.03	0.01	0.01	0.09	0.14
1830-1900	0.03	0.07	0.00	-0.01	0.02	0.03	0.02	0.05	0.00	0.01	0.40	0.37
1900-1930	0.04	0.06	0.00	-0.01	0.05	0.03	0.03	0.03	0.01	0.01	0.13	0.16
1930-2000	0.06	0.09	-0.01	-0.02	0.08	0.06	0.03	0.03	0.01	0.02	0.17	0.20
2000-2030	0.09	0.11	-0.01	-0.02	0.07	0.08	0.04	0.05	0.02	0.02	0.08	0.08
2030-2100	0.11	0.13	-0.02	-0.02	0.10	0.10	0.07	0.06	0.03	0.03	0.07	0.08
2100-2130	0.11	0.12	-0.02	-0.02	0.13	0.12	0.07	0.07	0.02	0.03	0.09	0.07
2130-2200	0.13	0.14	-0.02	-0.02	0.17	0.17	0.09	0.08	0.04	0.04	0.08	0.06
2200-2230	0.16	0.16	-0.03	-0.02	0.16	0.14	0.11	0.10	0.05	0.05	0.09	0.11
2230-2300	0.12	0.13	-0.02	-0.02	0.15	0.14	0.08	0.08	0.02	0.02	0.14	0.25
2300-2330	0.05	0.03	0.00	0.00	0.08	0.03	0.05	0.02	0.00	0.00	0.08	0.21
2330-2400	0.04	0.05	0.00	0.00	0.10	0.05	0.04	0.06	0.00	0.00	0.04	0.18
0000-0030	0.06	0.05	0.00	-0.01	0.04	0.02	0.06	0.05	0.00	0.01	0.13	0.10
0030-0100	0.05	0.07	0.00	-0.01	0.06	0.04	0.03	0.04	0.00	0.01	0.11	0.08
0100-0130	0.03	0.04	0.00	-0.01	0.02	0.03	0.02	0.02	0.00	0.00	0.04	0.07
0130-0200	0.03	0.04	0.00	0.00	0.05	0.06	0.02	0.04	0.00	0.00	0.12	0.12
0200-0230	0.03	0.02	0.00	0.00	0.05	0.07	0.01	0.02	0.00	0.00	0.12	0.13
0230-0300	0.27	0.03	0.06	0.00	0.74	0.10	0.06	0.21	0.01	0.00	0.50	0.34
0300-0330	0.11	0.03	0.01	0.00	0.25	0.13	0.02	0.02	0.00	0.00	0.14	0.21
0330-0400	0.04	0.05	-0.01	0.00	0.04	0.06	0.04	0.02	0.00	0.01	0.24	0.11
0400-0430	0.04	0.03	0.00	0.00	0.03	0.04	0.03	0.03	0.00	0.00	0.07	0.05
0430-0500	0.06	0.06	0.00	-0.01	0.04	0.04	0.05	0.03	0.01	0.01	0.18	0.08
0500-0530	0.04	0.04	-0.01	0.00	0.19	0.15	0.05	0.07	0.01	0.01	0.05	0.07
0530-0600	0.12	0.04	0.01	0.00	0.29	0.12	0.12	0.07	0.00	0.00	0.22	0.03
0600-0630	0.04	0.05	-0.01	0.00	0.07	0.04	0.05	0.09	0.01	0.01	0.08	0.36
Average:	0.08	0.08	0.00	-0.01	0.13	0.09	0.06	0.06	0.01	0.02	0.14	0.18

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Table 6. Mean values and turbulence statistics from two sonic anemometers at 5 and 2 m AGL on tower T3 for IOP7 (17–18 October 1999).

a. Mean values.

Time(CDT)	u (m/s) 5m	u (m/s) 2m	v (m/s) 5m	v (m/s) 2m	w (m/s) 5m	w (m/s) 2m	Spd (m/s) 5m	Spd (m/s) 2m	Wdir(deg) 5m	Wdir(deg) 2m	T (C) 5m	T (C) 2m
1800-1830	0.98	0.83	1.31	1.07	-0.08	-0.01	1.66	1.40	38.44	40.10	8.56	10.67
1830-1900	0.70	0.56	2.18	1.54	-0.13	-0.04	2.30	1.64	17.98	19.69	8.49	8.67
1900-1930	0.83	0.90	2.48	1.68	-0.15	-0.05	2.64	1.93	18.21	31.47	7.61	8.54
1930-2000	0.96	0.64	2.50	1.70	-0.16	-0.06	2.75	1.85	63.05	42.27	6.71	7.54
2000-2030	1.26	0.96	2.70	1.74	-0.15	-0.06	2.99	2.00	25.12	29.15	5.71	7.21
2030-2100	1.41	1.02	2.49	1.44	-0.14	-0.05	2.87	1.77	29.64	35.61	5.44	6.48
2100-2130	1.60	1.33	1.95	1.17	-0.11	-0.04	2.53	1.77	39.48	48.68	5.23	5.73
2130-2200	2.07	1.30	1.71	0.69	-0.10	-0.02	2.69	1.54	50.50	65.42	5.16	4.93
2200-2230	1.43	1.16	0.70	0.89	-0.08	-0.02	1.62	1.49	66.13	53.83	3.06	4.82
2230-2300	1.49	1.03	0.91	0.25	-0.07	0.00	1.78	1.08	60.70	77.49	3.54	4.33
2300-2330	1.17	0.99	-0.14	0.17	-0.07	0.00	1.19	1.01	96.65	80.39	2.20	3.94
2330-2400	1.17	0.99	-0.36	-0.32	-0.07	0.01	1.23	1.05	106.48	107.06	2.00	3.65
0000-0030	1.18	1.03	-0.62	-0.30	-0.06	0.01	1.34	1.09	118.19	106.08	1.47	3.00
0030-0100	1.73	1.25	-0.15	0.63	-0.07	-0.02	1.81	1.43	97.01	63.54	1.25	2.47
0100-0130	2.13	1.12	0.80	0.21	-0.09	-0.01	2.30	1.16	69.98	80.72	0.99	2.86
0130-0200	1.51	0.93	-0.15	-0.20	-0.05	0.00	1.54	0.97	96.34	102.13	1.55	3.66
0200-0230	1.41	1.05	-0.45	-0.26	-0.03	0.01	1.50	1.10	107.94	103.59	1.89	4.53
0230-0300	1.54	1.08	-0.47	-0.08	-0.02	0.00	1.63	1.10	106.62	93.89	2.36	4.92
0300-0330	1.46	1.01	-0.36	-0.14	-0.02	0.00	1.52	1.04	103.87	97.98	2.79	5.33
0330-0400	1.48	1.02	-0.37	-0.03	-0.02	-0.01	1.53	1.03	104.06	91.36	3.15	5.14
0400-0430	1.39	1.21	-0.39	-0.16	-0.03	0.00	1.45	1.22	105.63	97.21	3.21	5.21
0430-0500	1.47	1.29	-0.65	-0.03	-0.01	0.00	1.61	1.29	113.71	91.40	3.30	4.81
0500-0530	1.55	1.42	-0.44	-0.12	-0.03	0.00	1.62	1.44	106.32	94.53	2.75	3.57
0530-0600	2.33	1.50	-0.60	-0.41	-0.04	0.01	2.41	1.58	104.34	106.48	1.33	2.73
Average:	1.43	1.07	0.61	0.46	-0.07	-0.02	1.94	1.37	76.93	73.34	3.74	5.20

b. Turbulence statistics.

Time(CDT)	ustar(m/s) 5m	ustar(m/s) 2m	w'T'(Km/s) 5m	w'T'(Km/s) 2m	u'u' 5m	u'u' 2m	v'v' 5m	v'v' 2m	w'w' 5m	w'w' 2m	T'T' 5m	T'T' 2m
1800-1830	0.03	0.07	0.00	0.00	0.11	0.09	0.10	0.12	0.00	0.01	0.10	0.21
1830-1900	0.01	0.04	0.00	0.00	0.16	0.05	0.02	0.02	0.00	0.01	0.11	0.34
1900-1930	0.04	0.09	-0.01	-0.02	0.09	0.14	0.15	0.08	0.01	0.02	0.28	0.37
1930-2000	0.10	0.10	0.00	-0.02	0.20	0.12	0.38	0.12	0.01	0.03	1.15	0.53
2000-2030	0.09	0.12	-0.02	-0.02	0.06	0.09	0.06	0.06	0.02	0.03	0.15	0.13
2030-2100	0.07	0.08	-0.01	-0.01	0.04	0.06	0.04	0.05	0.01	0.01	0.10	0.14
2100-2130	0.03	0.05	0.00	-0.01	0.01	0.02	0.04	0.02	0.00	0.01	0.05	0.13
2130-2200	0.02	0.08	0.00	-0.01	0.04	0.15	0.01	0.16	0.00	0.01	0.15	0.26
2200-2230	0.08	0.05	0.01	0.00	0.12	0.06	0.06	0.05	0.00	0.00	0.31	0.08
2230-2300	0.07	0.04	0.01	0.00	0.11	0.01	0.09	0.06	0.00	0.00	0.22	0.06
2300-2330	0.04	0.02	0.00	0.00	0.02	0.02	0.02	0.01	0.00	0.00	0.02	0.03
2330-2400	0.05	0.02	0.00	0.00	0.03	0.03	0.02	0.02	0.00	0.00	0.03	0.03
0000-0030	0.04	0.03	0.00	0.00	0.03	0.04	0.01	0.02	0.00	0.00	0.04	0.22
0030-0100	0.06	0.09	0.00	-0.01	0.11	0.05	0.29	0.07	0.00	0.01	0.09	0.08
0100-0130	0.07	0.09	-0.01	-0.01	0.08	0.08	0.11	0.06	0.01	0.01	0.21	0.08
0130-0200	0.02	0.06	0.00	0.00	0.02	0.03	0.06	0.03	0.00	0.01	0.09	0.13
0200-0230	0.05	0.08	0.00	0.00	0.04	0.05	0.05	0.03	0.01	0.01	0.03	0.05
0230-0300	0.07	0.10	0.00	-0.01	0.04	0.06	0.06	0.04	0.01	0.02	0.02	0.02
0300-0330	0.07	0.08	0.00	-0.01	0.04	0.04	0.04	0.02	0.01	0.01	0.04	0.03
0330-0400	0.06	0.05	0.00	0.00	0.03	0.03	0.02	0.02	0.01	0.01	0.02	0.05
0400-0430	0.03	0.02	0.00	0.00	0.03	0.01	0.01	0.02	0.00	0.00	0.01	0.03
0430-0500	0.02	0.02	0.00	0.00	0.01	0.02	0.01	0.01	0.00	0.00	0.02	0.05
0500-0530	0.05	0.04	0.00	-0.01	0.02	0.04	0.03	0.03	0.00	0.00	0.14	0.45
0530-0600	0.08	0.14	-0.02	-0.02	0.17	0.17	0.04	0.08	0.02	0.03	0.31	0.07
Average:	0.05	0.06	0.00	-0.01	0.07	0.06	0.07	0.05	0.01	0.01	0.15	0.15

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Table 7. Mean values and turbulence statistics from two sonic anemometers at 5 and 2 m AGL on tower T3 for IOP8 (19–20 October 1999).

a. Mean values.

Time(CDT)	u (m/s) 5m	u (m/s) 2m	v (m/s) 5m	v (m/s) 2m	w (m/s) 5m	w (m/s) 2m	Spd (m/s) 5m	Spd (m/s) 2m	Wdir (deg) 5m	Wdir (deg) 2m	T (C) 5m	T (C) 2m
1700-1730	-1.38	-0.95	1.52	1.25	-0.16	-0.05	2.10	1.62	317.16	322.20	11.75	14.40
1730-1800	-0.67	-0.32	1.83	1.35	-0.16	-0.04	1.96	1.39	339.79	346.62	11.01	13.00
1800-1830	-0.49	-0.12	1.84	1.47	-0.15	-0.04	1.92	1.49	345.02	354.88	10.24	11.64
1830-1900	-0.04	0.16	1.88	1.49	-0.15	-0.04	1.90	1.50	247.34	285.15	10.12	11.66
1900-1930	0.59	0.74	2.12	1.42	-0.13	-0.02	2.20	1.60	15.59	27.54	10.23	11.49
1930-2000	0.39	0.49	2.20	1.34	-0.14	-0.03	2.24	1.44	10.05	26.80	9.53	10.03
2000-2030	1.23	1.24	0.22	-0.08	0.00	0.03	1.80	1.42	82.35	89.24	7.35	7.98
2030-2100	1.88	1.79	-0.78	-0.21	0.01	0.01	2.04	1.81	112.67	96.94	6.28	7.51
2100-2130	1.84	1.77	-0.57	-0.22	-0.01	0.01	1.93	1.78	107.07	96.92	5.30	7.27
2130-2200	1.94	1.74	-0.14	0.08	-0.03	0.00	1.96	1.76	94.11	87.11	4.54	6.44
2200-2230	1.97	1.74	-0.25	-0.12	-0.02	0.00	2.02	1.77	97.07	93.94	4.27	6.09
2230-2300	2.06	1.76	-0.41	-0.18	-0.02	0.01	2.10	1.78	101.20	95.82	3.59	5.56
2300-2330	1.73	1.62	-0.68	-0.36	-0.01	0.01	1.88	1.68	111.76	103.00	3.53	5.41
2330-2400	1.89	1.79	-0.55	-0.11	-0.02	0.00	1.98	1.80	106.17	93.70	3.23	5.00
0000-0030	1.68	1.65	-1.04	-0.50	0.00	0.02	1.98	1.73	121.88	106.81	3.03	4.60
0030-0100	1.60	1.59	-1.27	-0.50	0.01	0.02	2.05	1.67	128.17	107.53	3.18	4.80
0100-0130	1.72	1.74	-1.42	-0.63	0.03	0.02	2.24	1.86	129.37	109.74	3.73	5.38
0130-0200	1.23	1.22	-1.54	-0.63	0.04	0.03	1.98	1.39	141.25	116.88	3.62	5.26
0200-0230	1.16	1.38	-1.86	-0.91	0.05	0.03	2.20	1.66	148.16	123.45	3.92	5.35
0230-0300	0.99	1.14	-2.01	-0.99	0.07	0.04	2.25	1.52	153.61	131.12	4.07	5.42
0300-0330	0.85	0.88	-2.29	-1.28	0.08	0.04	2.46	1.59	158.80	144.52	4.46	6.16
0330-0400	0.54	0.67	-2.41	-1.28	0.08	0.04	2.48	1.46	167.47	152.24	4.83	6.51
0400-0430	0.76	0.85	-2.72	-1.48	0.11	0.05	2.84	1.73	164.33	150.46	5.12	6.64
0430-0500	0.48	0.62	-2.68	-1.51	0.11	0.05	2.73	1.65	169.86	157.90	4.84	6.52
0500-0530	0.63	0.81	-3.13	-1.87	0.11	0.05	3.20	2.06	168.57	156.44	4.70	6.34
0530-0600	0.25	0.54	-2.96	-1.85	0.09	0.05	2.98	1.95	175.11	163.51	4.22	6.07
0600-0630	0.04	0.26	-2.77	-1.73	0.08	0.04	2.80	1.78	179.56	171.87	3.99	5.91
0630-0700	-0.41	-0.04	-3.15	-2.18	0.07	0.05	3.19	2.20	187.44	181.08	4.06	6.29
Average:	0.87	0.96	-0.82	-0.37	0.00	0.01	2.26	1.68	152.89	146.19	5.67	7.31

b. Turbulence statistics.

Time(CDT)	ustar(m/s) 5m	ustar(m/s) 2m	w'T'(Km/s) 5m	w'T'(Km/s) 2m	u'u' 5m	u'u' 2m	v'v' 5m	v'v' 2m	w'w' 5m	w'w' 2m	T'T' 5m	T'T' 2m
1700-1730	0.17	0.15	-0.02	-0.02	0.18	0.15	0.21	0.16	0.06	0.04	0.09	0.20
1730-1800	0.07	0.07	-0.01	-0.01	0.11	0.06	0.03	0.02	0.02	0.01	0.05	0.15
1800-1830	0.04	0.03	0.00	0.00	0.02	0.01	0.03	0.03	0.00	0.00	0.15	0.44
1830-1900	0.04	0.03	0.00	0.00	0.01	0.01	0.05	0.02	0.00	0.00	0.01	0.22
1900-1930	0.02	0.02	0.00	0.00	0.03	0.02	0.00	0.01	0.00	0.00	0.04	0.30
1930-2000	0.05	0.03	0.00	0.00	0.02	0.04	0.04	0.03	0.00	0.00	0.04	0.53
2000-2030	0.28	0.08	-0.10	-0.02	0.04	0.16	1.73	0.40	0.01	0.00	2.84	1.88
2030-2100	0.04	0.03	0.01	0.00	0.02	0.02	0.02	0.01	0.00	0.00	0.43	0.08
2100-2130	0.02	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.20	0.08
2130-2200	0.06	0.06	0.00	-0.01	0.04	0.04	0.06	0.05	0.01	0.01	0.06	0.09
2200-2230	0.07	0.07	-0.01	-0.01	0.05	0.05	0.13	0.07	0.01	0.01	0.11	0.10
2230-2300	0.06	0.08	0.00	-0.01	0.05	0.04	0.03	0.03	0.01	0.01	0.04	0.08
2300-2330	0.05	0.05	0.00	0.00	0.02	0.02	0.08	0.06	0.00	0.00	0.04	0.06
2330-2400	0.04	0.03	0.00	0.00	0.01	0.01	0.04	0.03	0.00	0.00	0.03	0.07
0000-0030	0.01	0.02	0.00	0.00	0.00	0.01	0.03	0.02	0.00	0.00	0.13	0.08
0030-0100	0.04	0.02	0.00	0.00	0.02	0.01	0.03	0.01	0.00	0.00	0.06	0.06
0100-0130	0.04	0.03	0.00	0.00	0.01	0.01	0.03	0.03	0.00	0.00	0.05	0.08
0130-0200	0.02	0.02	0.00	0.00	0.05	0.02	0.02	0.03	0.00	0.00	0.03	0.10
0200-0230	0.02	0.03	0.00	0.00	0.03	0.03	0.03	0.02	0.00	0.00	0.05	0.06
0230-0300	0.08	0.06	-0.01	-0.01	0.05	0.03	0.03	0.03	0.01	0.01	0.09	0.15
0300-0330	0.09	0.09	-0.01	-0.01	0.17	0.08	0.09	0.12	0.02	0.02	0.15	0.23
0330-0400	0.10	0.09	-0.01	-0.02	0.07	0.06	0.04	0.05	0.02	0.02	0.12	0.12
0400-0430	0.10	0.10	-0.01	-0.02	0.08	0.08	0.05	0.07	0.02	0.02	0.11	0.10
0430-0500	0.13	0.13	-0.02	-0.02	0.17	0.21	0.04	0.05	0.02	0.02	0.12	0.13
0500-0530	0.11	0.13	-0.01	-0.02	0.08	0.09	0.04	0.06	0.02	0.03	0.16	0.15
0530-0600	0.11	0.13	-0.02	-0.02	0.09	0.09	0.06	0.06	0.03	0.03	0.10	0.09
0600-0630	0.10	0.11	-0.01	-0.02	0.11	0.09	0.14	0.13	0.02	0.02	0.07	0.09
0630-0700	0.16	0.16	-0.02	-0.02	0.22	0.18	0.09	0.10	0.06	0.06	0.08	0.07
Average:	0.08	0.07	-0.01	-0.01	0.06	0.06	0.11	0.06	0.01	0.01	0.19	0.21

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Table 8. Mean values and turbulence statistics from two sonic anemometers at 5 and 2 m AGL on tower T3 for IOP9 (20–21 October 1999).

a. Mean values.

Time(CDT)	u (m/s) 5m	u (m/s) 2m	v (m/s) 5m	v (m/s) 2m	w (m/s) 5m	w (m/s) 2m	Spd (m/s) 5m	Spd (m/s) 2m	Wdir (deg) 5m	Wdir (deg) 2m	T (C) 5m	T (C) 2m
1700-1730	-2.73	-1.97	-3.43	-2.54	0.04	0.04	4.42	3.27	218.89	217.39	18.78	21.50
1730-1800	-1.13	-0.60	-2.09	-1.18	0.01	0.03	2.40	1.34	208.09	206.71	16.65	18.73
1800-1830	-0.53	-0.31	-1.42	-0.50	0.00	0.01	1.53	0.63	201.34	219.99	15.75	17.77
1830-1900	-0.55	-0.20	-0.97	-0.49	-0.02	0.02	1.29	0.89	217.07	221.98	14.64	16.81
1900-1930	0.62	0.90	-1.91	-0.67	0.09	0.06	2.02	1.14	161.84	125.86	13.92	15.31
1930-2000	1.25	1.47	-1.74	-0.61	0.07	0.06	2.16	1.60	144.34	112.91	12.57	13.92
2000-2030	1.56	1.62	-2.18	-1.08	0.07	0.06	2.70	2.00	144.49	124.49	12.33	13.48
2030-2100	0.14	0.29	-2.17	-1.07	0.06	0.05	2.19	1.14	176.86	169.11	12.00	13.62
2100-2130	0.77	0.82	-1.98	-0.73	0.07	0.05	2.16	1.19	157.59	126.61	11.41	12.66
2130-2200	0.23	0.29	-1.13	-0.45	0.01	0.04	1.20	0.69	169.13	170.68	10.08	12.30
2200-2230	-0.23	-0.01	-2.44	-1.58	0.04	0.05	2.48	1.61	184.91	179.67	11.05	13.32
2230-2300	-0.64	-0.38	-2.67	-1.79	0.05	0.05	2.77	1.86	193.82	192.75	11.26	13.66
2300-2330	-0.57	-0.28	-2.11	-1.37	0.03	0.03	2.21	1.42	195.35	191.20	10.86	13.23
2330-2400	-0.29	-0.03	-2.35	-1.56	0.05	0.06	2.39	1.59	187.26	181.18	10.68	13.06
0000-0030	0.05	0.24	-2.51	-1.68	0.07	0.07	2.53	1.72	178.68	171.50	10.46	12.85
0030-0100	-0.35	-0.15	-2.86	-2.14	0.06	0.06	2.91	2.18	186.70	183.38	10.45	12.99
0100-0130	-1.04	-0.67	-3.56	-2.61	0.07	0.06	3.74	2.74	196.22	194.34	10.48	13.06
0130-0200	-0.99	-0.54	-2.46	-1.68	0.03	0.05	2.68	1.80	202.09	198.03	9.59	11.92
0200-0230	-0.66	-0.26	-2.16	-1.38	0.01	0.04	2.28	1.42	197.51	191.78	8.99	11.20
0230-0300	-0.71	-0.24	-2.53	-1.71	0.03	0.04	2.64	1.75	195.64	187.83	8.50	10.50
0300-0330	-0.41	-0.18	-2.21	-1.38	0.05	0.03	2.34	1.48	196.64	194.53	7.86	10.34
0330-0400	-1.02	-0.50	-1.77	-1.06	0.00	0.01	2.05	1.18	209.87	205.40	7.57	9.60
0400-0430	-0.90	-0.31	-2.06	-1.28	0.02	0.03	2.28	1.34	204.15	194.83	7.32	9.28
0430-0500	-0.79	-0.39	-1.98	-1.19	0.02	0.03	2.15	1.26	201.89	198.53	7.19	9.20
0500-0530	-1.27	-0.63	-1.21	-0.55	-0.02	0.00	1.77	0.87	227.03	229.80	6.69	8.68
0530-0600	-1.09	-0.48	-1.09	-0.64	-0.03	0.01	1.57	0.85	226.25	220.69	6.62	8.69
0600-0630	-0.35	0.31	-1.84	-0.99	0.04	0.04	1.94	1.18	190.01	162.55	6.62	8.38
0630-0700	0.17	0.85	-1.76	-0.74	0.05	0.04	1.77	1.16	174.32	130.28	6.49	8.31
Average:	-0.41	-0.05	-2.09	-1.24	0.04	0.04	2.31	1.48	191.00	182.28	10.60	12.66

b. Turbulence statistics.

Time(CDT)	ustar(m/s) 5m	ustar(m/s) 2m	w'T'(Km/s) 5m	w'T'(Km/s) 2m	u'u' 5m	u'u' 2m	v'v' 5m	v'v' 2m	w'w' 5m	w'w' 2m	T'T' 5m	T'T' 2m
1700-1730	0.35	0.35	-0.04	-0.05	1.33	1.28	0.31	0.36	0.17	0.13	0.30	0.58
1730-1800	0.11	0.08	-0.01	-0.01	0.17	0.11	0.08	0.04	0.02	0.01	0.23	0.31
1800-1830	0.08	0.03	0.00	0.00	0.16	0.08	0.04	0.04	0.01	0.01	0.18	0.12
1830-1900	0.18	0.12	0.00	0.11	0.19	0.22	0.38	0.48	0.01	0.08	0.21	0.82
1900-1930	0.06	0.07	-0.01	-0.01	0.11	0.10	0.03	0.04	0.01	0.00	0.25	0.50
1930-2000	0.08	0.06	0.01	0.00	0.04	0.05	0.11	0.05	0.01	0.00	0.30	0.31
2000-2030	0.06	0.08	0.00	-0.01	0.10	0.12	0.13	0.21	0.01	0.01	0.08	0.28
2030-2100	0.08	0.10	-0.01	-0.01	0.32	0.27	0.08	0.05	0.01	0.01	0.29	0.25
2100-2130	0.09	0.10	-0.01	-0.02	0.16	0.19	0.14	0.16	0.02	0.01	0.37	0.57
2130-2200	0.14	0.14	0.00	-0.01	0.63	0.44	0.08	0.05	0.02	0.01	0.28	0.24
2200-2230	0.14	0.15	-0.03	-0.03	0.18	0.17	0.14	0.11	0.04	0.03	0.23	0.35
2230-2300	0.18	0.17	-0.03	-0.04	0.31	0.29	0.13	0.11	0.07	0.05	0.16	0.23
2300-2330	0.14	0.12	-0.02	-0.02	0.16	0.11	0.11	0.08	0.06	0.03	0.14	0.16
2330-2400	0.16	0.13	-0.03	-0.03	0.20	0.16	0.11	0.09	0.06	0.04	0.09	0.12
0000-0030	0.16	0.16	-0.03	-0.03	0.23	0.19	0.12	0.10	0.06	0.05	0.12	0.14
0030-0100	0.18	0.19	-0.04	-0.04	0.32	0.33	0.20	0.17	0.08	0.07	0.11	0.14
0100-0130	0.26	0.24	-0.04	-0.04	0.49	0.40	0.24	0.21	0.13	0.10	0.11	0.12
0130-0200	0.16	0.16	-0.02	-0.03	0.29	0.20	0.15	0.13	0.05	0.04	0.15	0.17
0200-0230	0.09	0.09	-0.01	-0.01	0.32	0.14	0.07	0.05	0.03	0.02	0.13	0.17
0230-0300	0.11	0.11	-0.01	-0.02	0.13	0.13	0.07	0.10	0.02	0.02	0.14	0.18
0300-0330	0.19	0.10	-0.02	-0.02	0.89	0.48	0.36	0.23	0.05	0.03	0.08	0.09
0330-0400	0.08	0.06	-0.01	-0.01	0.07	0.05	0.04	0.02	0.01	0.01	0.08	0.11
0400-0430	0.08	0.08	-0.01	-0.01	0.12	0.12	0.11	0.05	0.01	0.01	0.11	0.14
0430-0500	0.08	0.07	-0.01	-0.01	0.12	0.08	0.07	0.04	0.01	0.01	0.09	0.11
0500-0530	0.08	0.07	-0.01	-0.01	0.07	0.07	0.07	0.06	0.02	0.01	0.09	0.14
0530-0600	0.08	0.06	-0.01	-0.01	0.10	0.10	0.09	0.08	0.01	0.01	0.10	0.16
0600-0630	0.11	0.09	0.00	-0.01	0.06	0.05	0.25	0.30	0.01	0.00	0.07	0.14
0630-0700	0.06	0.06	-0.01	-0.01	0.03	0.02	0.01	0.08	0.01	0.01	0.05	0.11
Average:	0.13	0.12	-0.01	-0.01	0.26	0.21	0.13	0.12	0.04	0.03	0.16	0.24

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Average values for each day are listed at the bottom of each table. For the intercomparison, the time series of wind direction (ψ), wind speed (S), air temperature (T), friction velocity (u_*) and kinematic heat flux (H) calculated from the two simultaneous data files are presented for each IOP. The figure names for the plots of this intercomparison are labeled as figures 7(a–g) through 13(a–g) in which subset a is for wind direction plot, b is for wind speed plot, c is for temperature plot, d is for friction velocity plot, e is for heat flux plot, f is for linear regression of friction velocity plot, and g is for linear regression of heat flux plot. These plots show such intercomparison between the two levels for each individual IOP from IOP3 through IOP9, respectively. The linear regression analysis, i.e.,

$$y = ax + b, \tag{22}$$

has also been performed (f and g plots) to determine the correlation of u_* and of H between the two levels, in which y is the measurement (u_* or H) from the 2-m level, and x is the measurement from the 5-m level. The a and b in equation (22) are the slope and intercept, respectively. Figure 14(a and b) shows combination of the linear regression for u_* and for H, respectively, for all nine IOPs.

3.1.1 Intercomparison of Mean Wind and Temperature

Figure 7(a–c) through 13(a–c) show the intercomparison of the mean wind direction, wind speed, and temperature between 2 and 5 m on the same tower (T3).

Through preliminary examination of these plots, figures 7b–13b show that the wind speeds at 2 m (dash line) are always smaller than that at the 5-m level (solid line). This means that the vertical wind speed shear in the surface layer is always greater than zero, which is common knowledge. However, the wind direction (fig. 7a–13a) at 2 and 5 m sometimes differ considerably. Those figures demonstrate that the vertical wind direction shear, $\Delta\psi$, can be either positive (clockwise from lower level to upper level, veering) or negative (counterclockwise, backing) (fig. 11a). The cases with strong vertical wind direction shear deserve further investigation because those cases are related to strong shear instability and represent significant departure from traditional similarity theory. The present report is not intended to provide detailed case analyses.

Detailed numerical values of the mean wind speed and direction for those eight IOPs are also listed in tables 2a–8a. The mean vertical velocity (w) listed in those eight tables was measured by the ARL sonic anemometers. The values of w are small but not equal to zero. The reasons for non-zero of mean vertical velocity might be twofold. One reason can be due to local topographic effects (terrain slope). Another can be the sampling error in turbulence measurements. As we have discussed in the previous section, the transformation to the mean streamline coordinates has made the transformed vertical velocity zero, see equation (12).

17
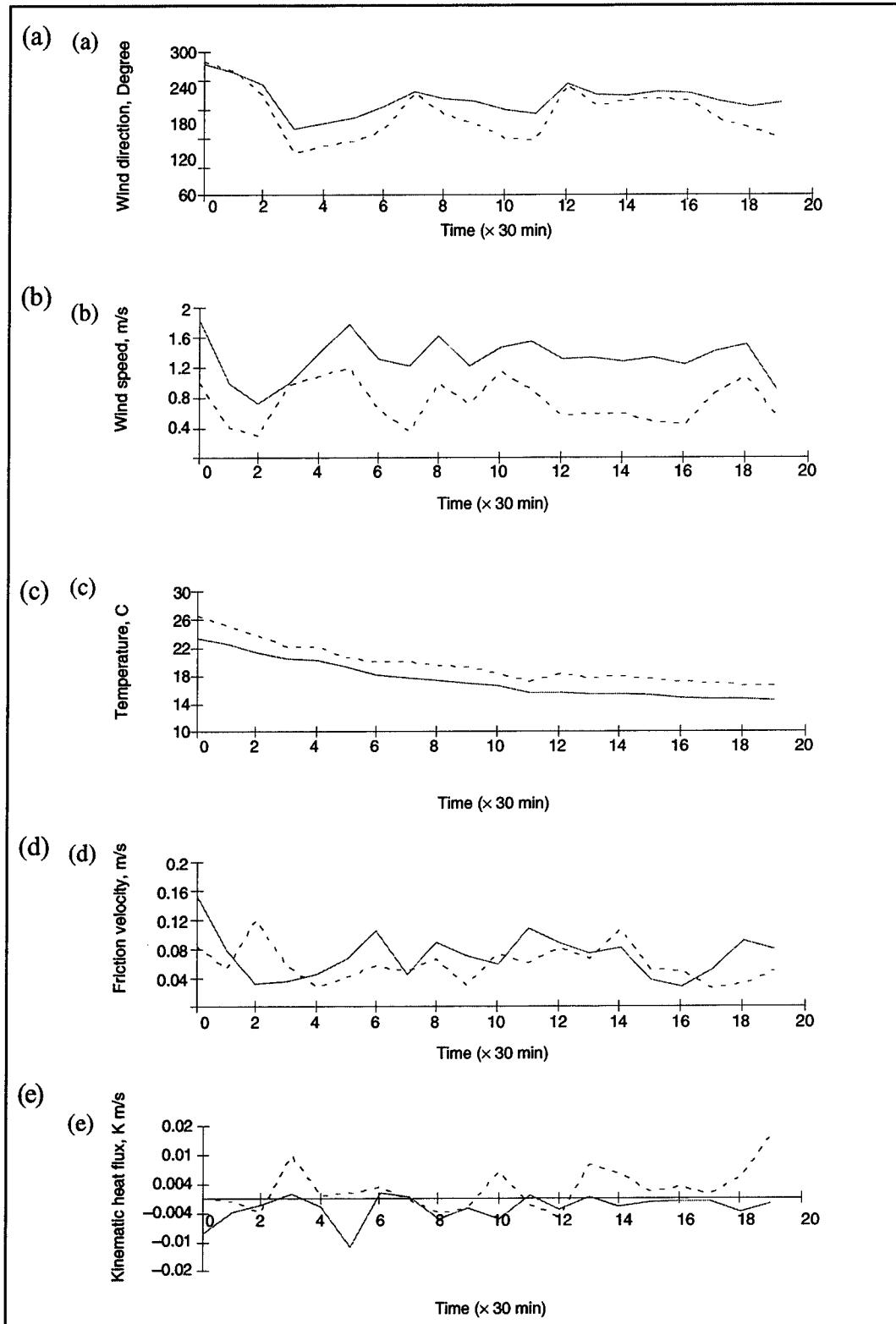
Figure 7. Time series (30-min averages) of (a) wind direction, (b) wind speed, (c) temperature, (d) friction velocity, and (e) kinematic heat flux at 5 m (solid line) and 2 m (dash line) AGL for IOP3 (9–10 October 1999) started at 1700 CDT.

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(f)

slope = 0.132
intercept = 0.051

(g)

slope = 0.331
intercept = –0.0038
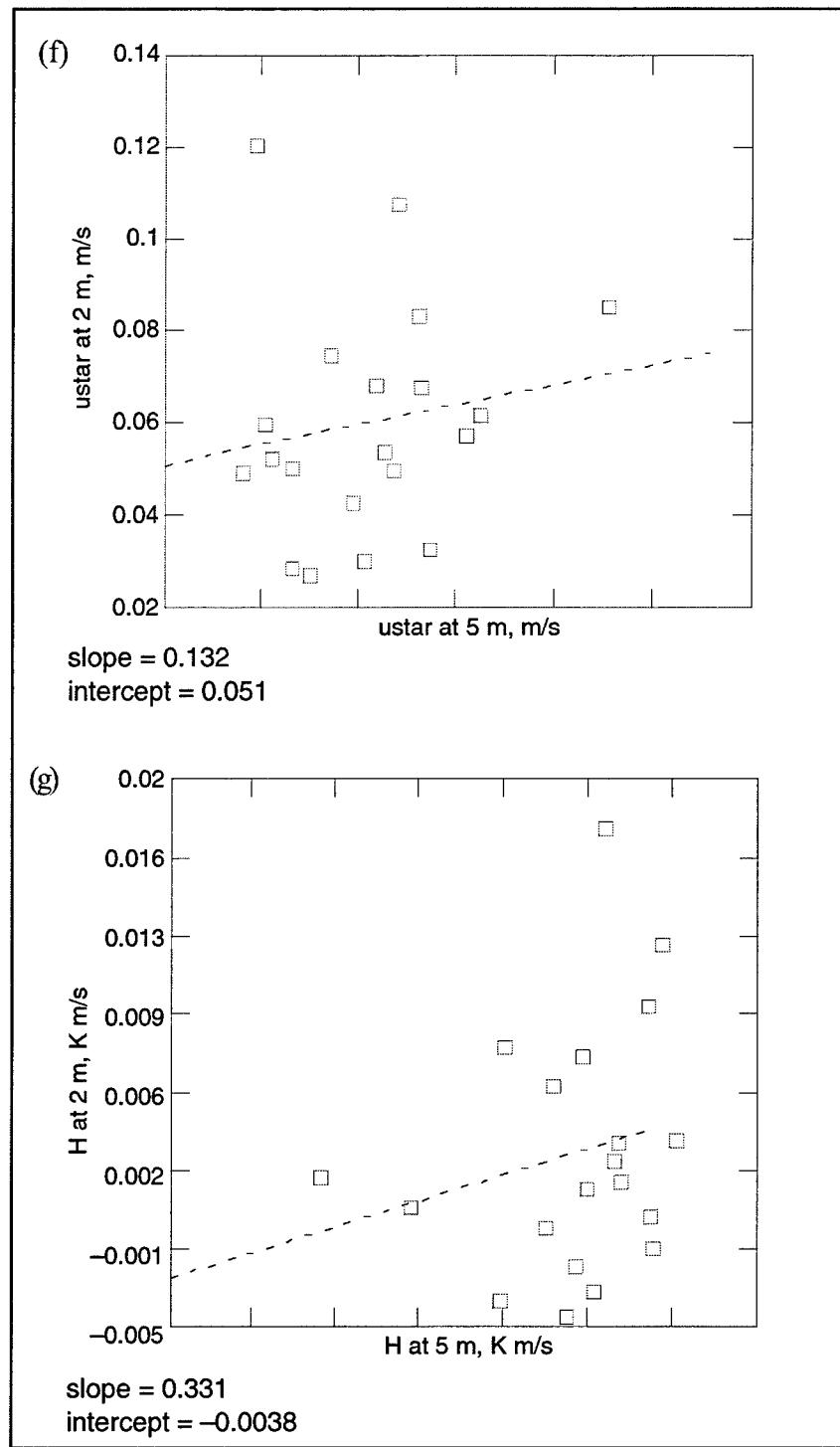
Figure 7 (cont'd). (f) linear regression at 5 m and 2 m AGL of friction
velocity u_*, and (g) kinematic heat flux H for IOP3
(9–10 October 1999), started at 1700 CDT.

19
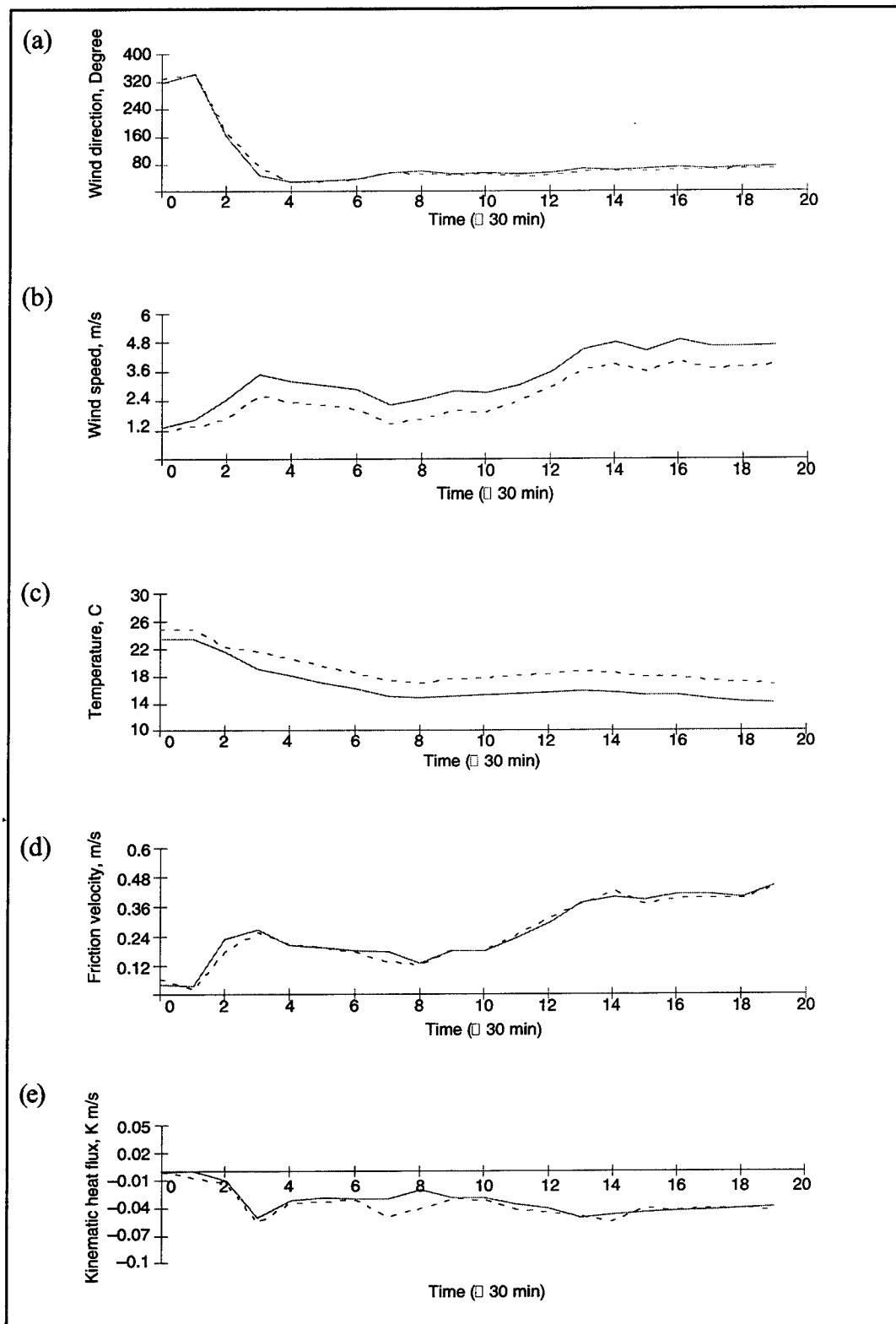
Figure 8. Time series (30-min averages) of (a) wind direction, (b) wind speed, (c) temperature, (d) friction velocity, and (e) kinematic heat flux at 5 m (solid line) and 2 m (dash AGL for IOP4 (10–11 October 1999) started at 1830 CDT.

(f)

slope = 0.999
intercept = 0.00023

(g)

slope = 0.9
intercept = −0.006
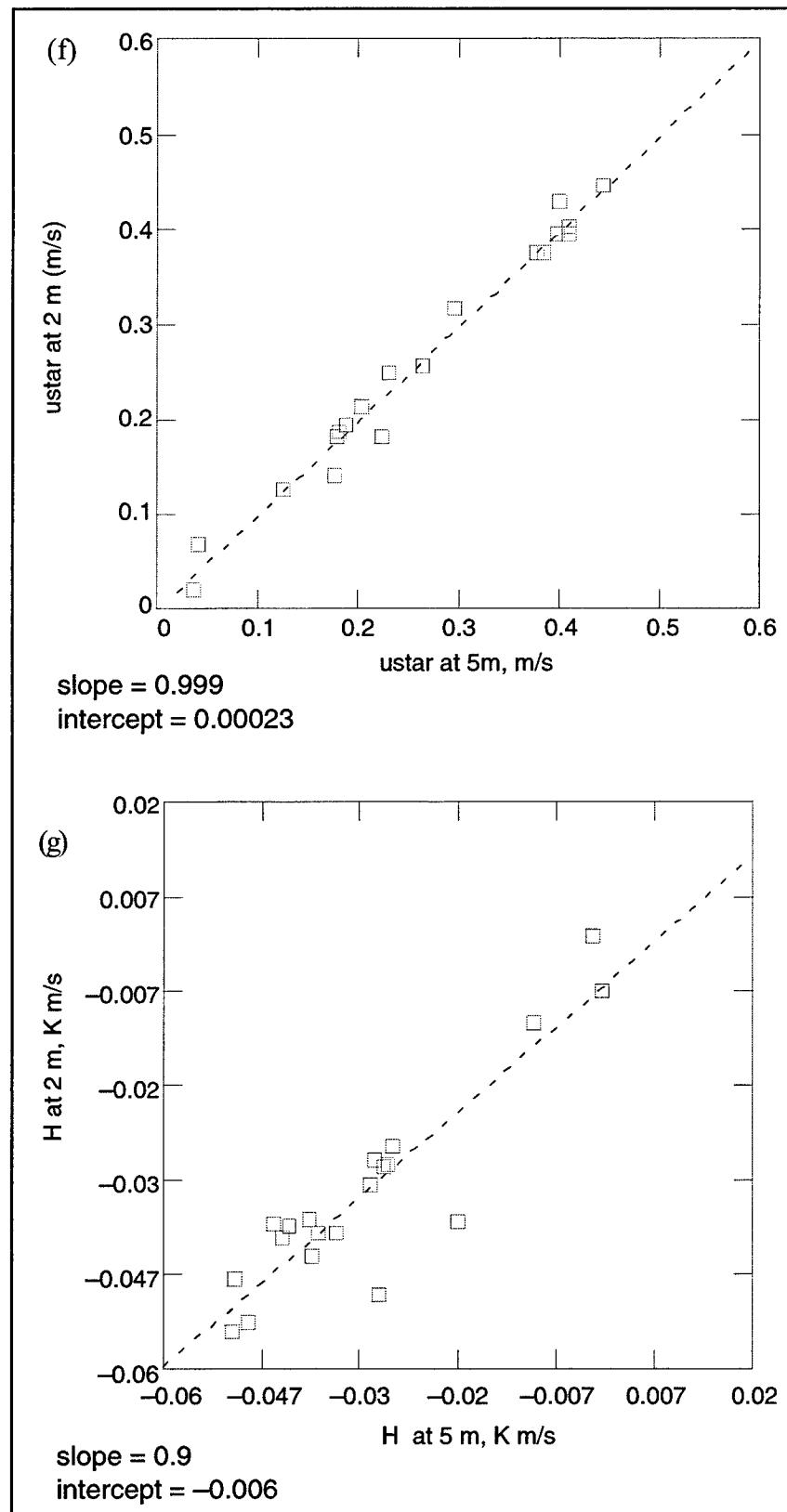
Figure 8 (cont'd). (f) linear regression at 5 m and 2 m AGL of friction velocity u_*, and (g) kinematic heat flux H for IOP4 (10–11 October 1999), started at 1830 CDT.
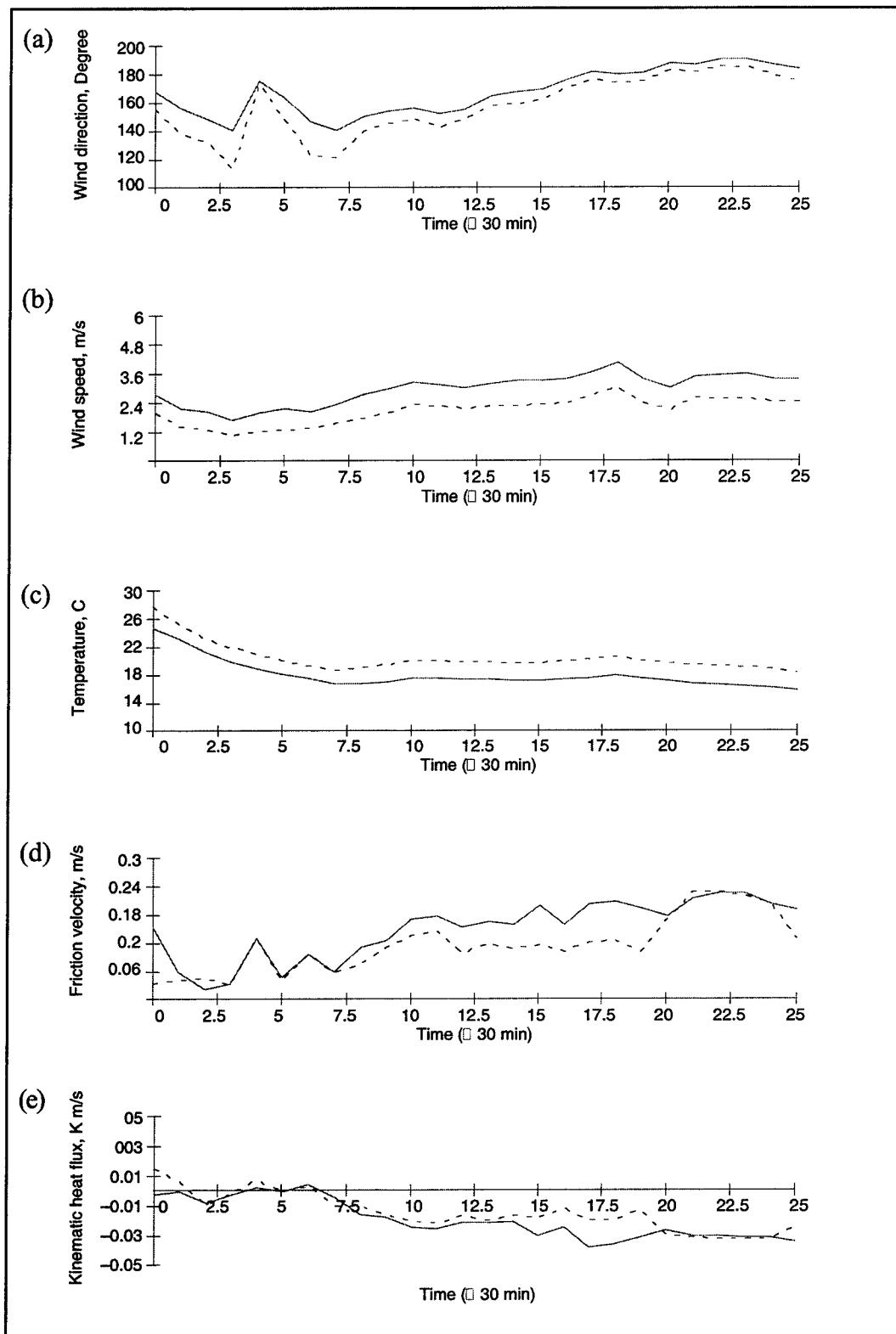
Figure 9. Time series (30-min averages) of (a) wind direction, (b) wind speed, (c) temperature, (d) friction velocity, and (e) kinematic heat flux at 5 m (solid line) and 2 m (dash line) AGL for IOP5 (11–12 October 1999) started at 1700 CDT.

22

(f) ... slope = 0.752
intercept = 0.00693

(g) ... slope = 0.844
intercept = 0.003
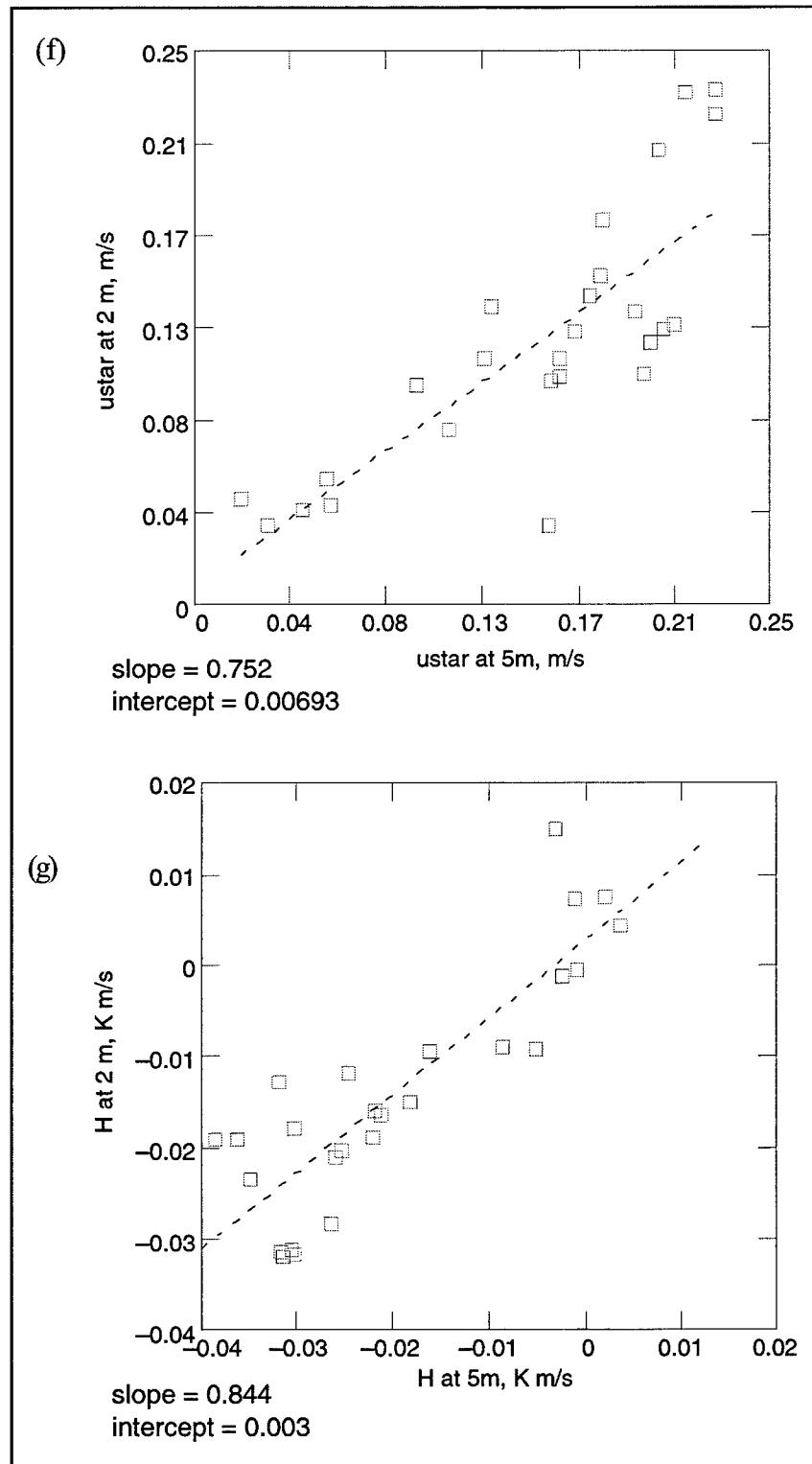
Figure 9 (cont'd). (f) linear regression at 5 m and 2 m AGL of friction velocity u_*, and (g) kinematic heat flux H for IOP5 (11–12 October 1999), started at 1700 CDT.

23
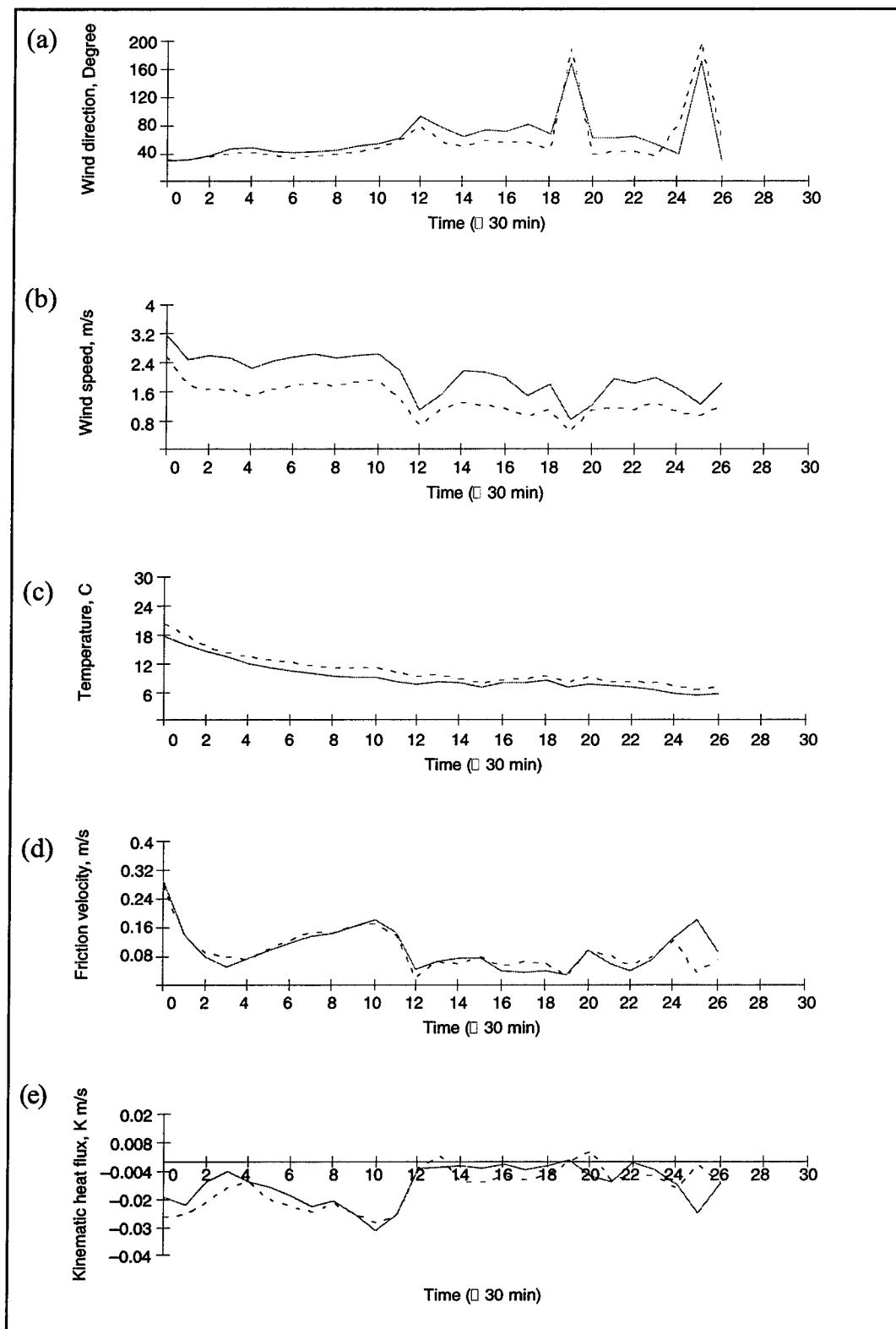
Figure 10. Time series (30-min averages) of (a) wind direction, (b) wind speed,
(c) temperature, (d) friction velocity, and (e) kinematic heat flux at 5 m (solid
line) and 2 m (dash line) AGL for IOP6 (13–14 October 1999) started at
1700 CDT.

24

(f)

slope = 0.775
intercept = 0.023

(g)

slope = 0.773
intercept = –0.003
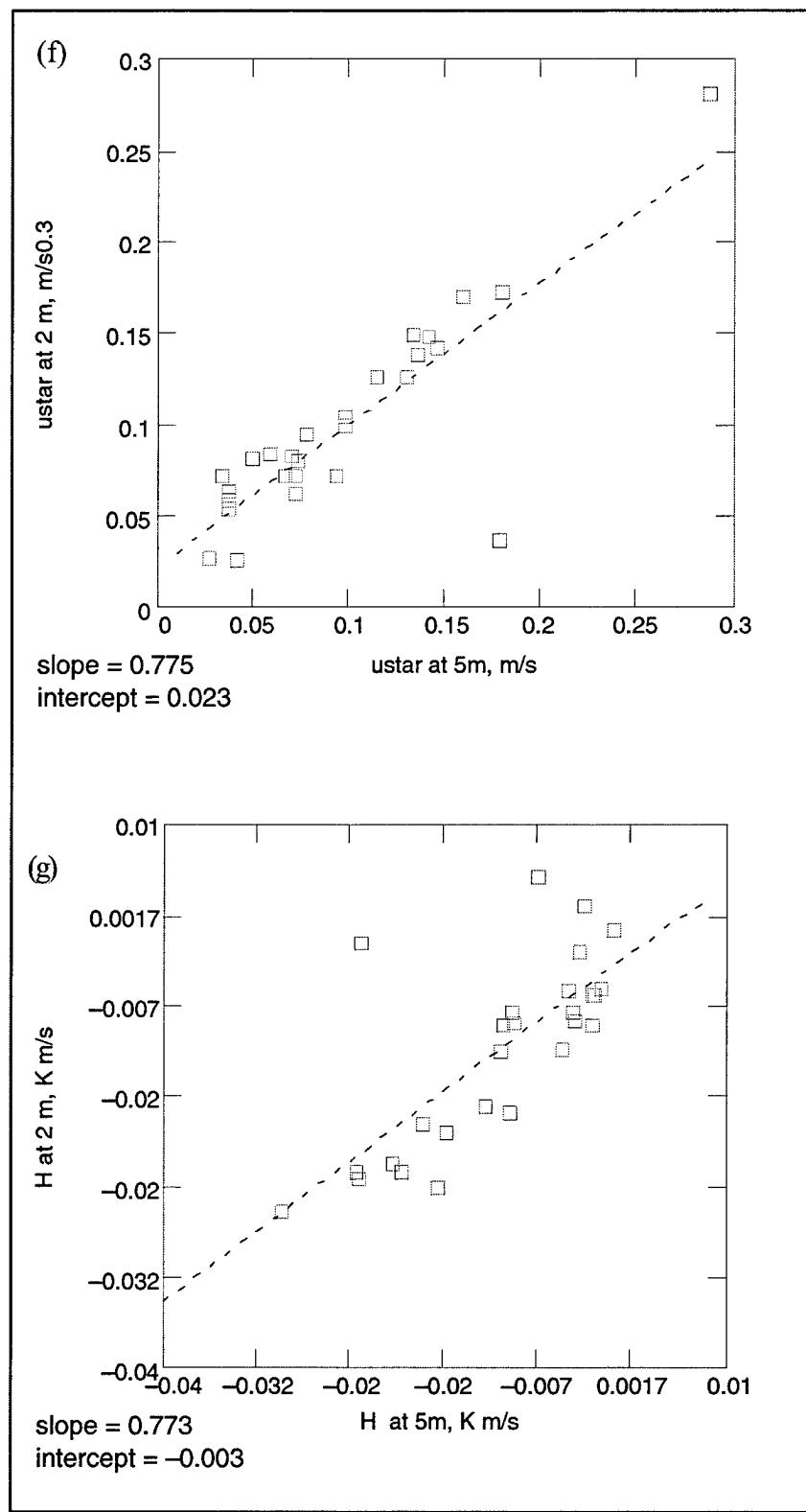
Figure 10 (cont'd). (f) linear regression at 5 m and 2 m AGL of friction velocity u_*, and (g) kinematic heat flux H for IOP6 (13–14 October 1999) after the removal of one overestimated data point at 0230–3000 CDT.
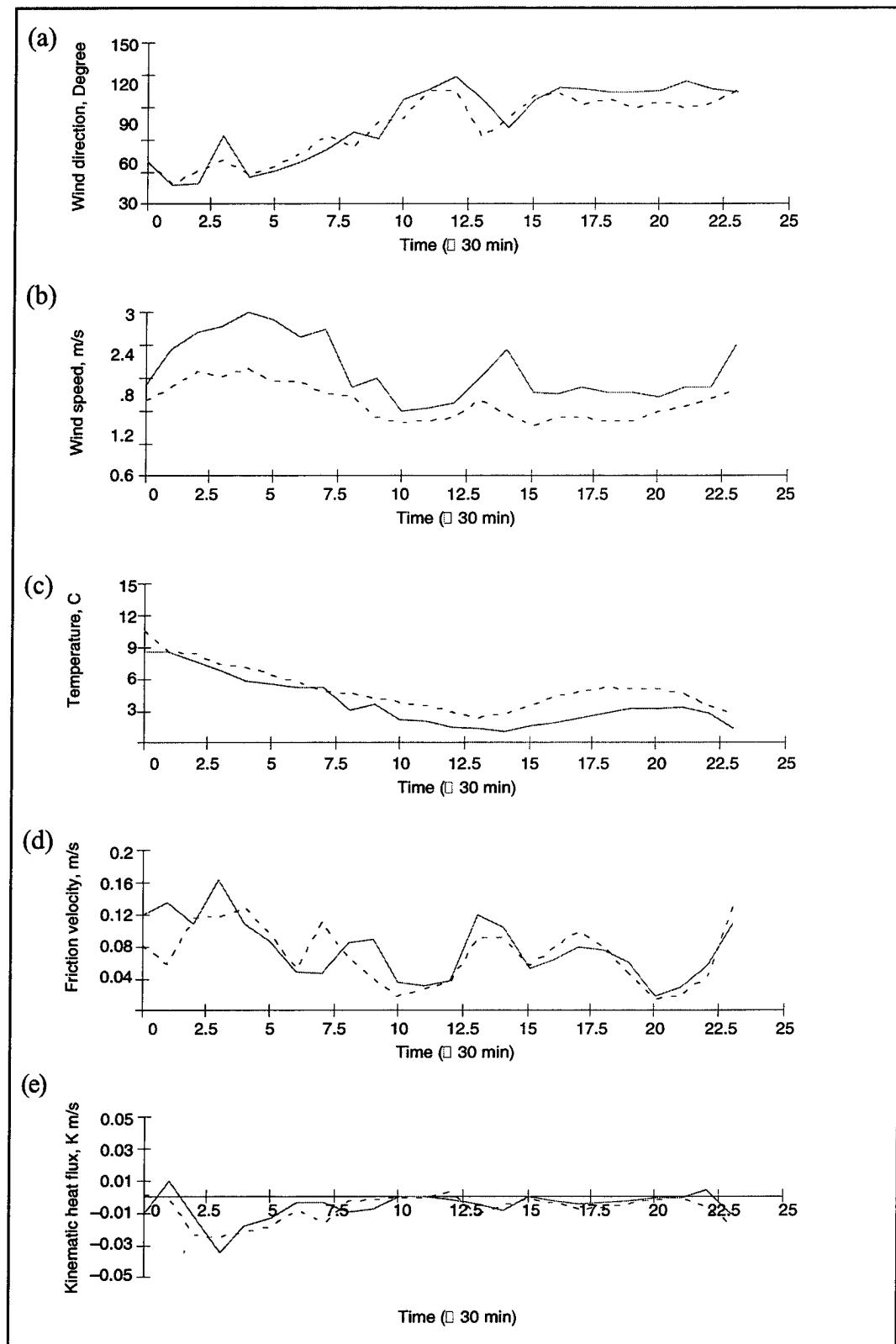
Figure 11. Time series (30-min averages) of (a) wind direction, (b) wind speed,
(c) temperature, (d) friction velocity, and (e) kinematic heat flux at 5 m (solid line)
and 2 m (dash line) AGL for IOP7 (17–18 October 1999) started at 1800 CDT.

26
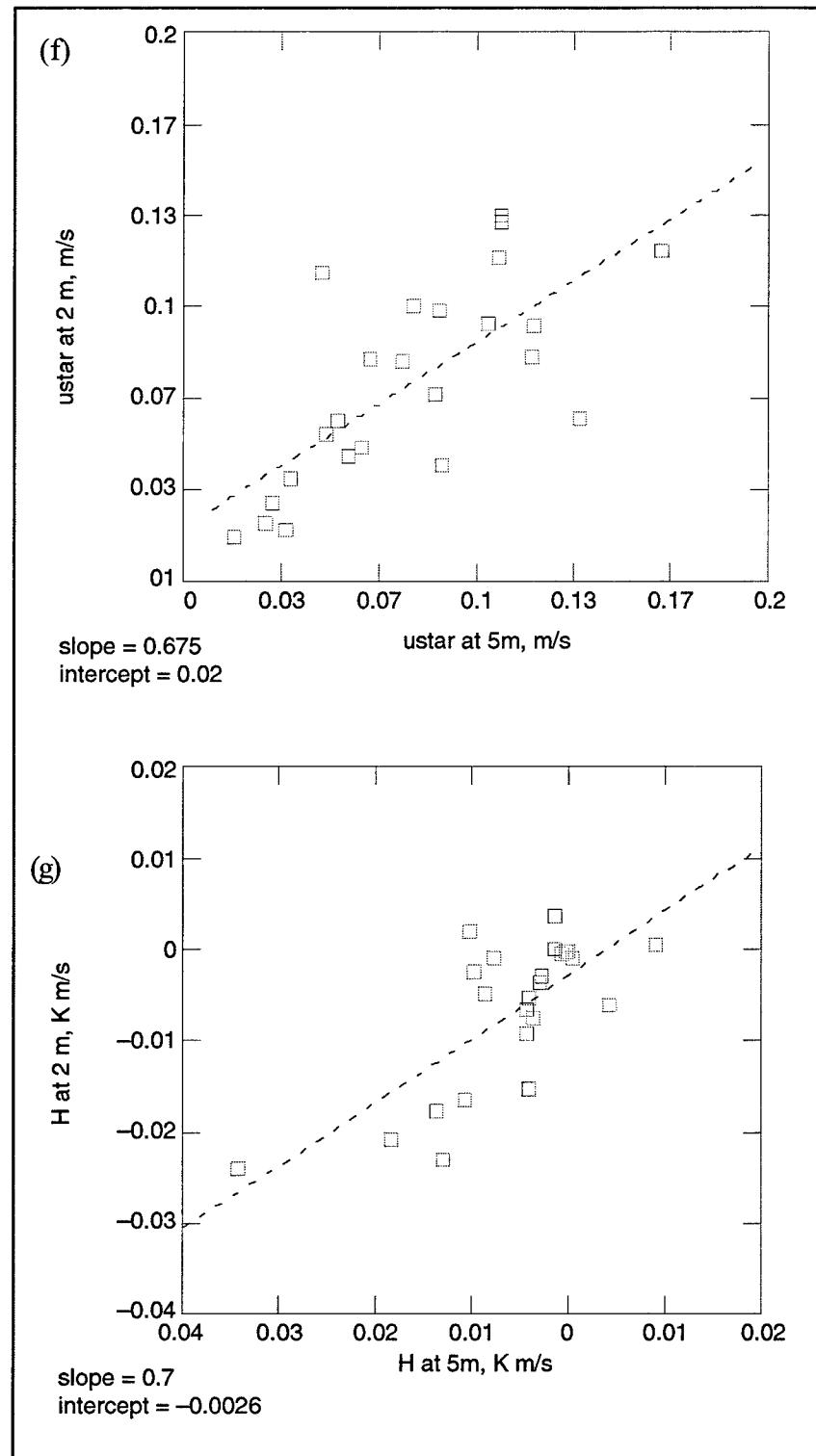
Figure 11 (cont'd). (f) linear regression at 5 m and 2 m AGL of friction velocity u_*, and (g) kinematic heat flux H for IOP7 (7–18 October 1999), started at 1800 CDT.

27
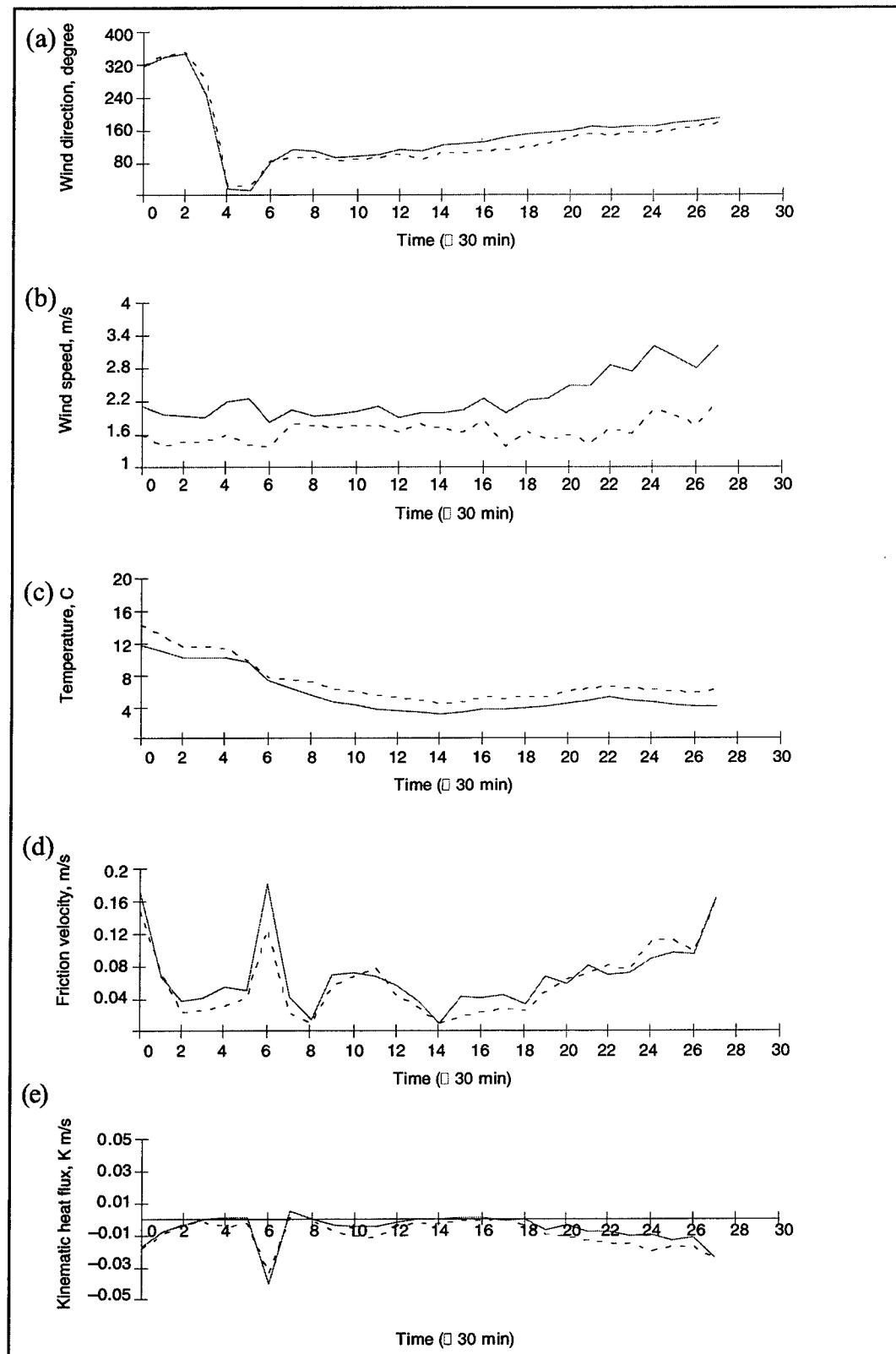
Figure 12. Time series (30-min averages) of (a) wind direction, (b) wind speed, (c) temperature, (d) friction velocity, and (e) kinematic heat flux at 5 m (solid line) and 2 m (dash line) AGL for IOP8 (19–20 October 1999) started at 1700 CDT.

28

(f)

slope = 0.918
intercept = −0.0004

(g)

slope = 0.864
intercept = −0.0032
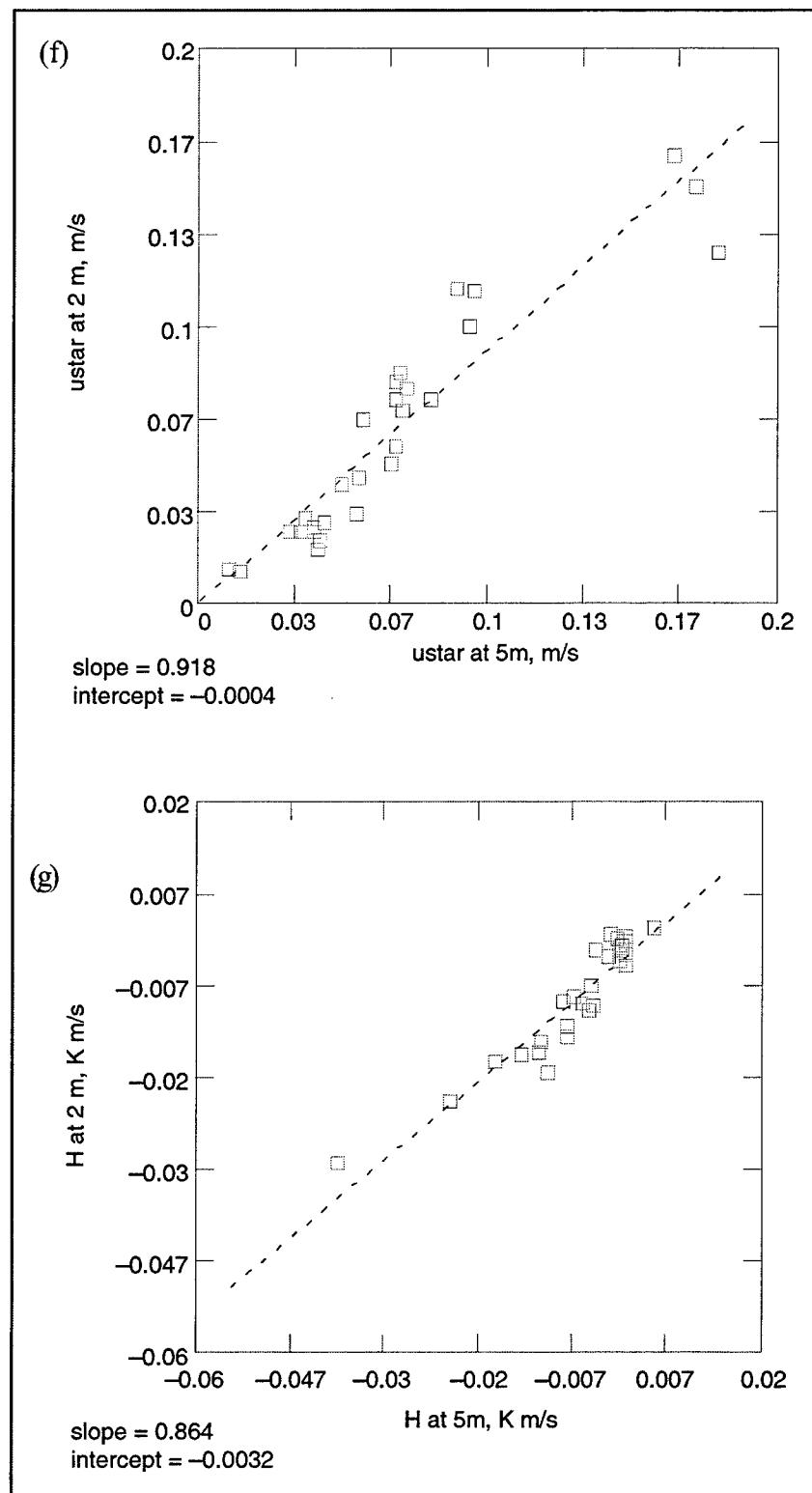
Figure 12 (cont'd). (f) linear regression at 5 m and 2 m AGL of friction
velocity u_*, and (g) kinematic heat flux H for IOP8 (19–20
October 1999) after the removal of one overestimated data
point at 2000–2030 CDT.

29
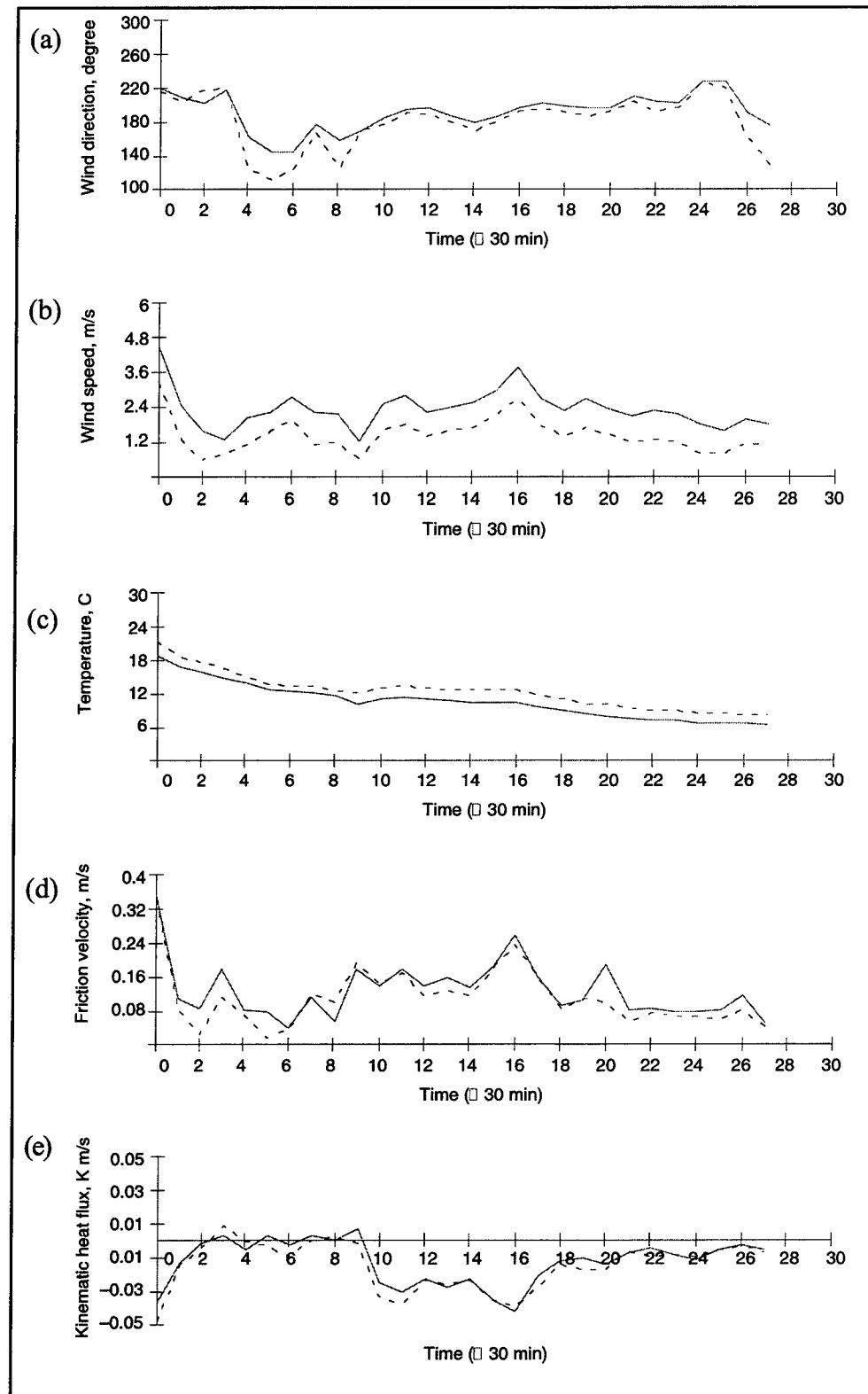
Figure 13. Time series (30-min averages) of (a) wind direction, (b) wind speed, (c) temperature, (d) friction velocity, and (e) kinematic heat flux at 5 m (solid line) and 2 m (dash line) AGL for IOP9 (20–21 October 1999) started at 1700 CDT.

30
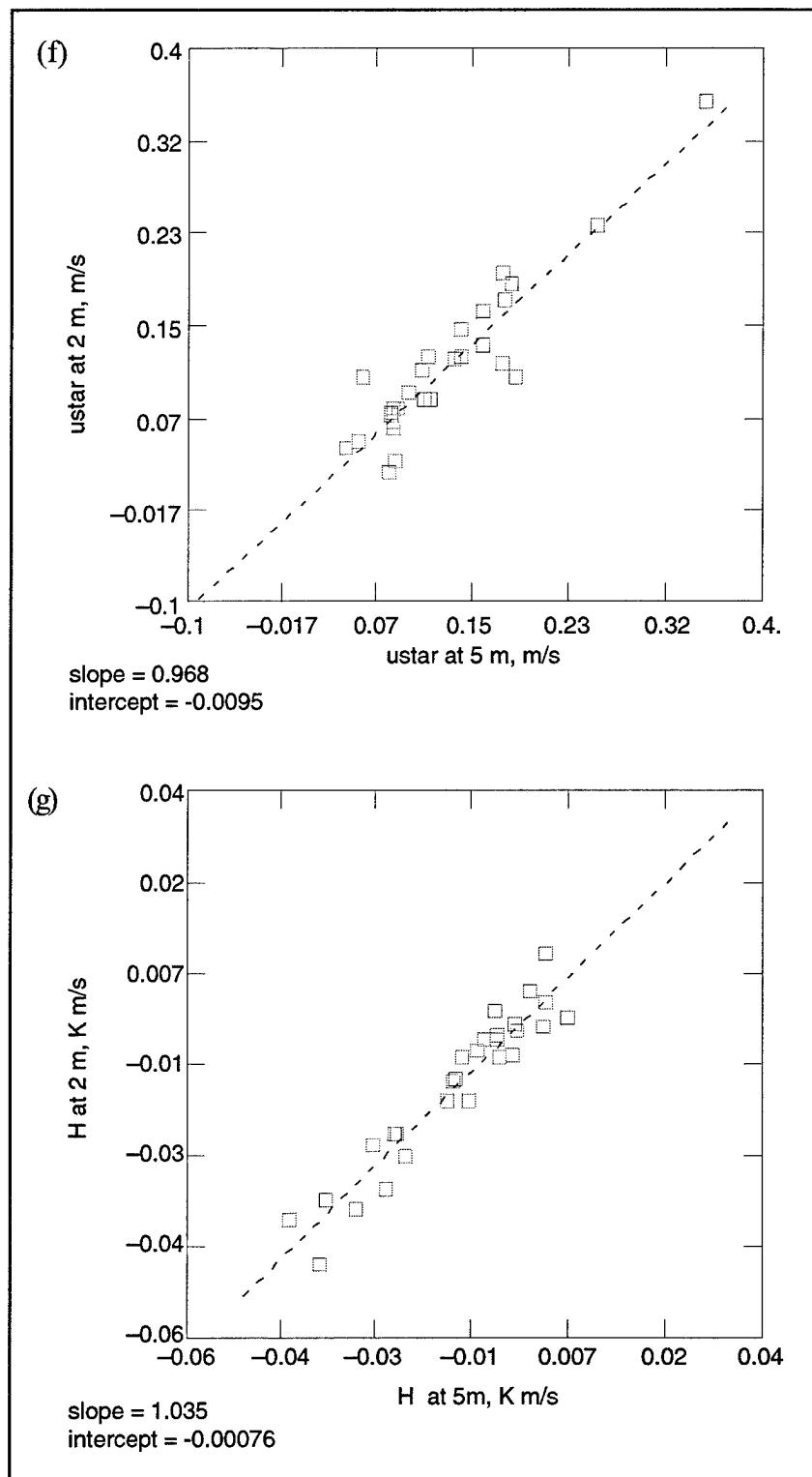
Figure 13 (cont'd). (f) linear regression at 5 m and 2 m AGL of friction velocity u_*, and (g) kinematic heat flux H for IOP9 (20–21 October 1999).
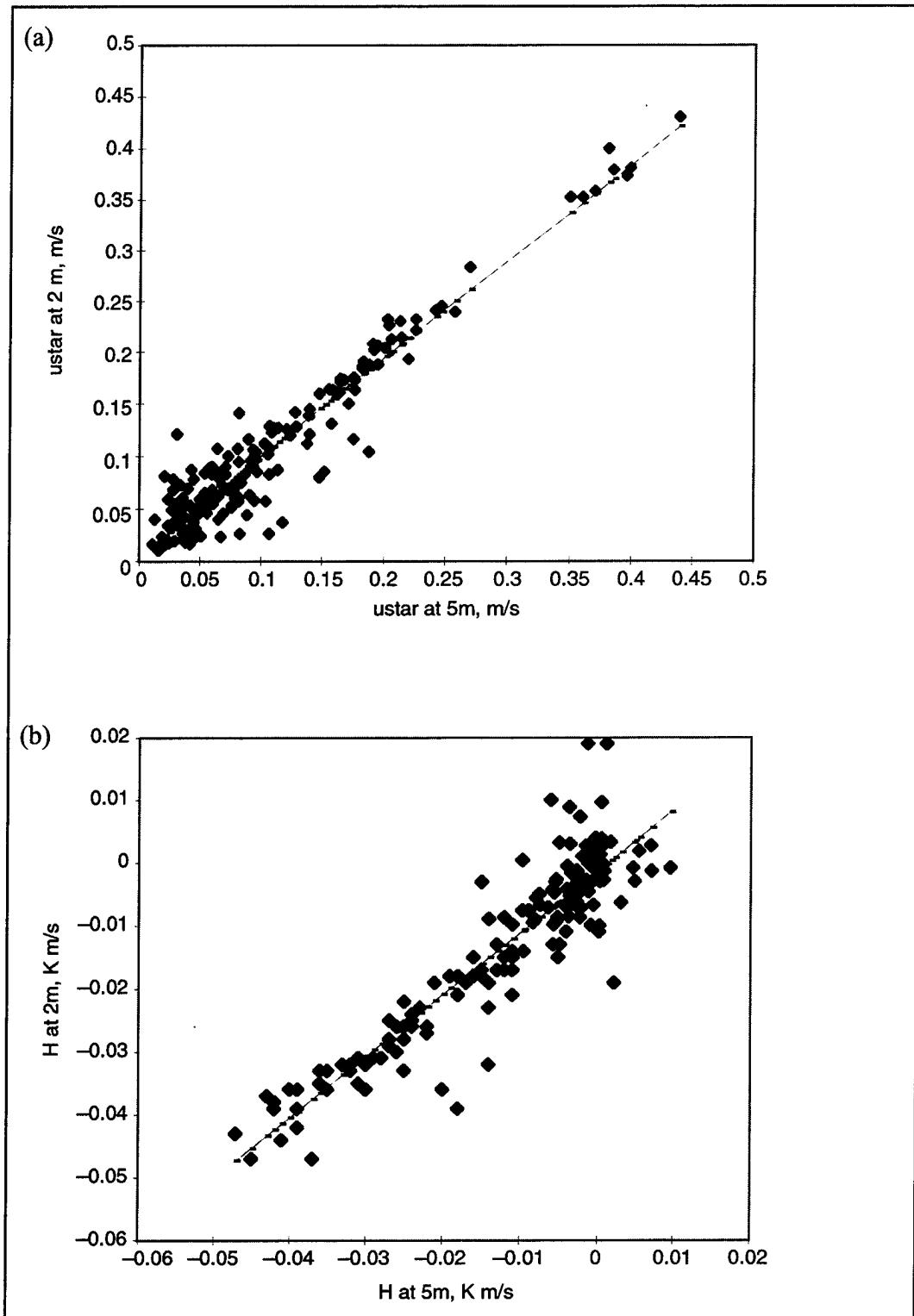
Figure 14. Combined linear regression of (a) friction velocity and (b) kinematic heat flux at 2 m versus 5 m for all IOPs.

Next, the temperature (fig. 7c–13c) at 2 m (dash line) appears always greater than the temperature at 5 m (solid line) except for only one case in IOP7, which occurred briefly during the half-hour (2130–2200 CDT) average on 17 October 1999 (fig. 11c). The magnitudes of the difference in temperature are mostly between 1.5 and 2.5 K. Consequently, it means that there were extremely large negative vertical temperature gradients ($\delta T/\delta z \ll 0$). As well known, the static stability (S_z) of the atmosphere can be expressed as

$$S_z = (1/T)\,(\Gamma + dT/dz) \ ,\tag{23}$$

where G is the adiabatic lapse rate (about 1 K/100 m) according to Fleagle and Businger (1980, p. 53). Figures 7c–13c indicate that S_z was always negative, or in other words, the lowest layer between 2 and 5 m was always unstable for those eight IOPs expected for that half-hour. Such results are obviously wrong and imply that the temperature measurements at one of the two levels or both were not reliable. Further investigation was conducted by comparing temperature readings at the same AGL from the ARL sonic anemometers and from other sonic anemometers deployed around the main 55-m tower. The result revealed that temperature data collected at 5 m on tower T3 were reasonably close to those collected near the main tower. The temperatures collected at the 2-m level, however, were unusually larger than the rest. In addition, it has been found later that the sonic anemometer at 2 m AGL had not been properly calibrated on the site during the field experiment. Therefore, it is concluded that the mean temperature at 2 m AGL on tower T3 was not reliable. It should be pointed out, however, that the errors in the mean temperature have insignificant effects on the calculation of temperature fluctuation (T'), hence on the calculation of turbulent heat fluxes $\left(\overline{w'T'}\right)$.

3.1.2 Intercomparison of Friction Velocity and Heat Flux

Figures 7(d and e) through 13(d and e) illustrate the intercomparison of the friction velocity (u_*, representing the turbulent momentum flux) and of the heat flux (H) at 2 m (dash line) and 5 m (solid line) on tower T3. The basic premise for the intercomparison of turbulent fluxes is that the divergence of the turbulent fluxes in the atmospheric surface layer should be negligible, i.e.,

$$\partial u_*/\partial z \simeq 0 \quad \text{or} \quad \Delta u_* = |u_*(2\text{ m}) - u_*(5\text{ m})| \simeq 0 \ ;\tag{24}$$

$$\partial H/\partial z \simeq 0 \quad \text{or} \quad \Delta H = |H(2\text{ m}) - H(5\text{ m})| \simeq 0 \ .\tag{25}$$

If there is a big difference in u_* or H between 2 and 5 m, then it should be explainable. Otherwise, the measurement or the calculation of the fluxes is questionable. A small difference in u_* or H between those two levels can usually be attributed to either sampling errors or insignificant flux divergences. Figures 7(f and g) through 13(f and g) are the plots for the linear regression (equation [22]) of these two turbulent quantities.

Figures 7d through 13d show that equation (24) is almost always true for those seven IOPs. It is more obvious for IOP4 and IOP5, while less obvious for IOP3 and IOP7. The possible reasons for relatively large Δu_* in IOP3 and IOP7 could include there were many spikes in sonic data from the 2-m level or weak and unsteady winds at 2 m. There are two cases (case A and case B) with big Δu_*. Case A occurred at 0230–0300, on 14 October 1999 in IOP6 in which u_* (5 m) = 0.27 m/s, while u_* (2 m) = 0.03 m/s (table 5b and fig. 10d). Case B occurred at 2000–2030 on 19 October 1999 in IOP8 in which u_* (5 m) = 0.28 m/s while u_* (2 m) = 0.13 m/s (table 7b and fig.

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12d). After careful inspection, the values of u_* (5 m) in both cases are believed to be overestimated at these particular points. Figure 15 illustrates the reason for this overestimation.

As in figure 15, the average value of u or v for a time period T ($\bar{u}$ or $\bar{v}$) is very close to zero. Consequently, the turbulent component (u' or v') of velocity appears to be very large, as seen from equation (13). Therefore, the estimated value of u_* would also be unreasonably large, (equation (14)). For the two cases previously mentioned, the corresponding values of $\overline{u'^2}$ and $\overline{v'^2}$ at 5 m are 0.74 m^{2}s^{-2} and 0.06 m^{2}s^{-2}, respectively, for case A, and 0.04 m^{2}s^{-2} and 1.73 m^{2}s^{-2}, respectively, for case B. It is concluded that those values of u_*, $\overline{u'^2}$ and $\overline{v'^2}$ are not reliable, and hence are excluded in the regression analyses.
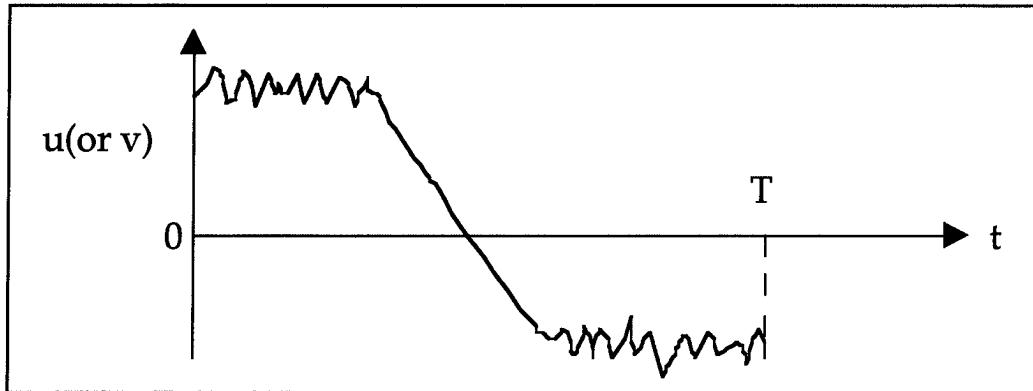
Figure 15. An illustration of the overestimation of u' or v'.

Similarly, figures 7e–13e show that equation (25) is almost always true for each of the seven IOPs. It should be pointed out that the turbulent heat flux in the stable (nocturnal) boundary layer is usually small and downward. Consequently, the sampling error for H can be relatively large. Hence H(5 m) and H(2 m) sometimes can have opposite directions (negative and positive values), e.g., as seen from figure 7e. As discussed earlier, the values of H for cases A and B are not reliable, and therefore, are excluded from linear regression analyses. The value of H(2 m) at 1830–1900 on 20 October 1999 in IOP9 is 0.11 Kms^{-1}, which is unbelievably large. The reason for this is yet to be determined.

Finally, figure 14(a and b) shows the linear regression plots of friction velocity (u_*) and heat flux (H) from the measurements of the two levels on tower T3 for all seven IOPs. Generally speaking, this combination plotting indicates that our sonic anemometer data are consistent and reasonably good quality.

3.2 Intercomparison of Measurements at the 2-m Level Among Four Towers

As shown in figure 5, five 5-m towers denoted as T1, T2, T3, T4, and T5 have been deployed by ARL during CASES-99. Each of these five towers was equipped with a sonic anemometer at 2 m AGL. The sonic data from T5, however, unfortunately have too many spikes, and hence, are useless (Noble 2000). Consequently, only data sets collected at the 2-m level from the remaining four towers can be compared. As mentioned earlier, the four towers are aligned in a N-S direction with approximately 200-m short distance of separation. If the terrain were completely flat, it could be anticipated that there should be no significant variation of meteorological elements at the 2-m level from these four locations.

Figures 16–22 present the intercomparisons of mean wind and temperature as well as turbulence quantities measured at the 2-m level from sonic anemometers at T1, T2, T3, and T4. The corresponding numerical values for the intercomparison are listed in tables 9–15. Notice that the data from T1 are not available for IOP3 and IOP7 while the data from T4 are not available for IOP3 and IOP8. First, it can be observed from figures 17c–20c that the air temperatures measured at T1 appear consistently cooler than at the other three locations by 3–4 K. This situation can hardly be explained except for the measurement errors at T1. This is probably due to incorrect temperature calibration at T1. Second, both wind direction and wind speed appear almost the same for T2 and T3. There were, however, significant differences between T1 and at the other locations. For example, the wind speed appeared lower at T1 than at the other three locations for IOP3, IOP6, and IOP8, while higher for IOP9. The wind direction at T1 also seems different from other three locations for IOP8 and IOP9, as shown in figures 21 and 22. This microscale variation of wind speed and direction could be induced by local topography. A high resolution wind model has been developed at ARL and has been successfully applied to study the microscale wind field variation caused by terrain effect (Cionco and Chang 2000). This model, known as the HRW (High-Resolution Wind) model, will be used to simulate CASES-99 wind field and other turbulence quantities in order to explain the observed differences in wind speed and direction.

The intercomparisons of turbulence statistics as shown in figures 16–22 indicate a complex situation. Sometimes there were insignificant differences of these turbulence quantities among the four locations. For example, u_*, H, and other turbulence statistics are almost the same around midnight in IOP4 and IOP8, as seen in figures 17 and 21. On the other hand, there were significant differences in u_*, H, etc., around midnight in IOP5. So far, there is a lack of theory to explain such microscale variation of turbulence statistics.
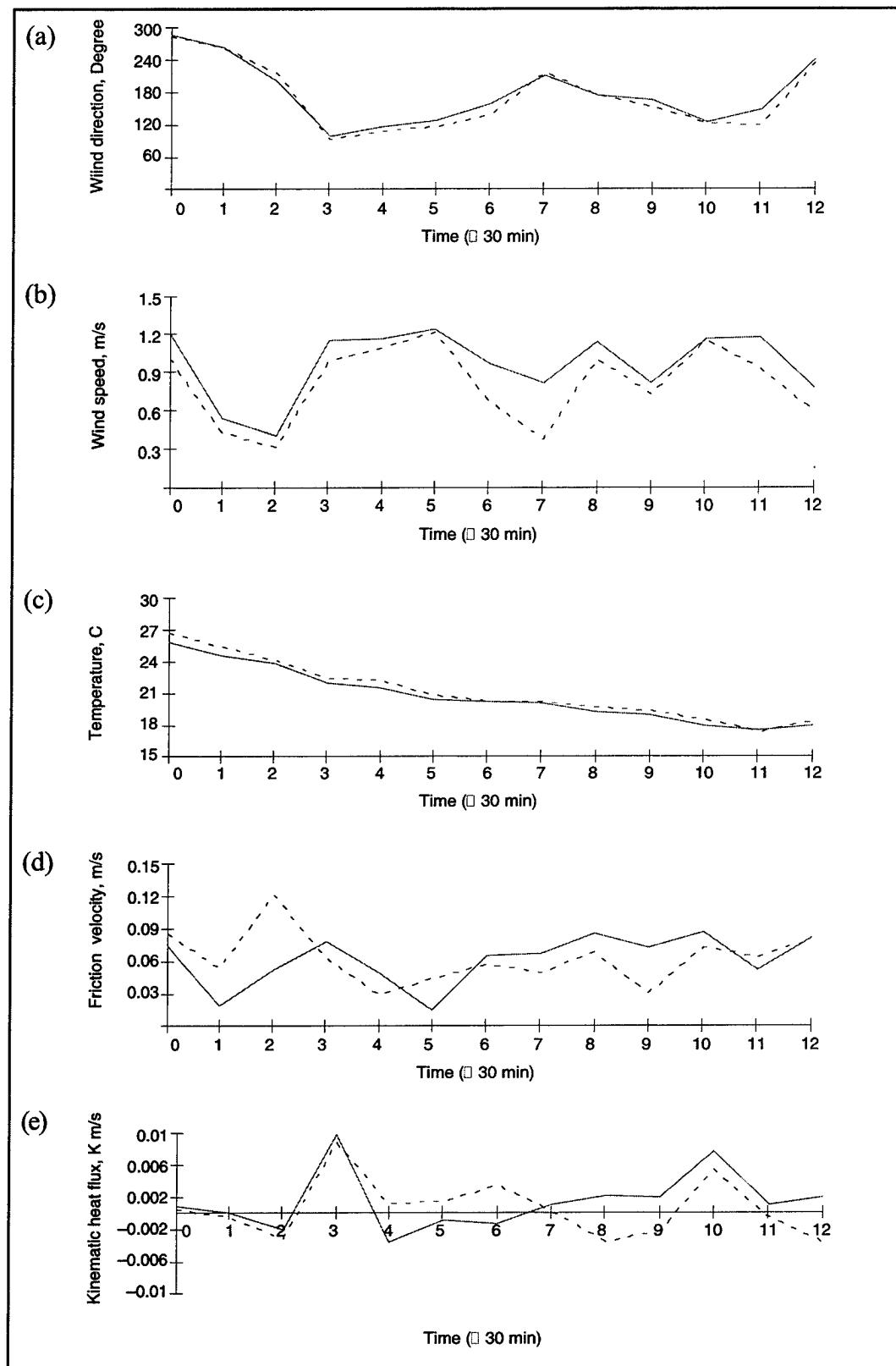
Figure 16. Time series (30-min averages) of (a) wind direction, (b) wind speed, (c) temperature , (d) friction velocity, and (e) kinematic heat flux at 2 m tower 2 (solid line) and Tower 3 (dash line) for IOP3 (9–10 October 1999) started at 1700 CDT.

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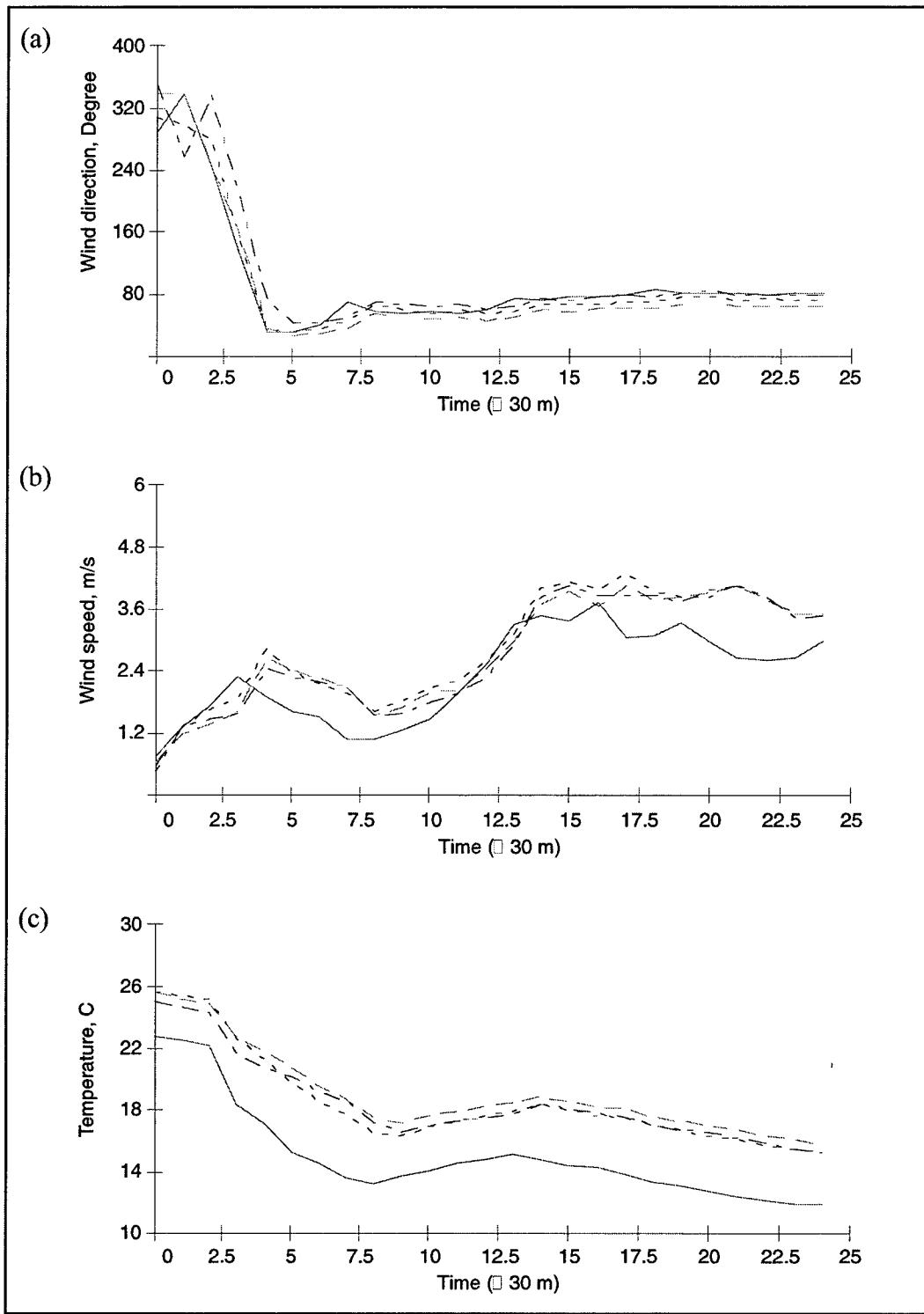
Figure 17. Time series (30-min averages) of (a) wind direction, (b) wind speed,
(c) temperature at 2 m tower 1 (solid line), tower 2 (dot), tower 3 (dash), and
tower 4 (dadot) IOP4 (10–11 October 1999) started at 1800 CDT.
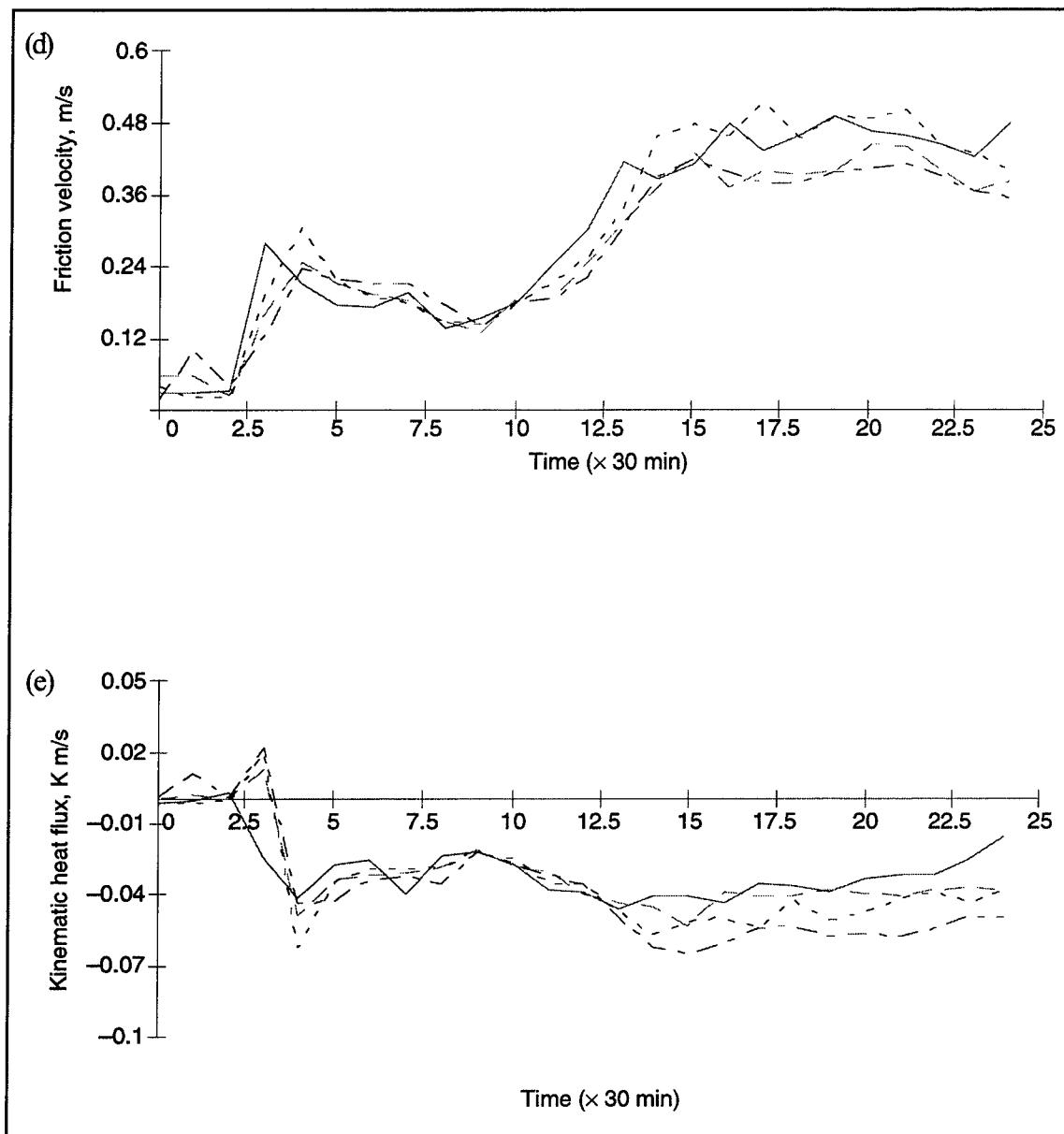
Figure 17 (cont'd). Time series (30-min averages) of (d) friction velocity, and (e) kinematic heat flux at 2 m tower 1 (solid line), tower 2 (dot), tower 3 (dash), and tower 4 (dadot) for IOP4 (10–11 October 1999) started at 1800 CDT.
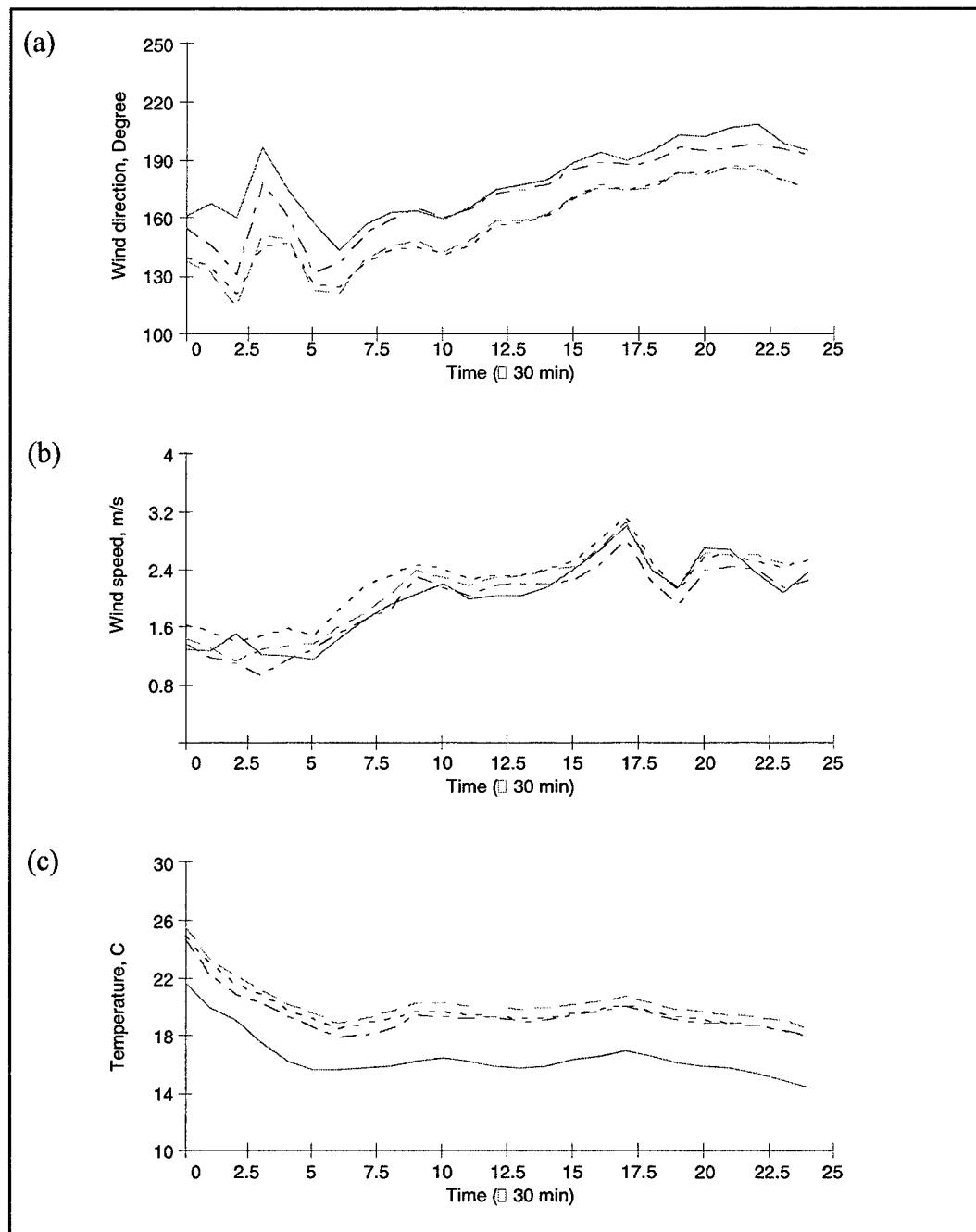
Figure 18. Time series (30-min averages) of (a) wind direction, (b) wind speed,
(c) temperature at 2 m tower 1 (solid line), tower 2 (dot), tower 3 (dash), and
tower 4 (dadot) for IOP5 (11–12 October 1999) started at 1730 CDT.
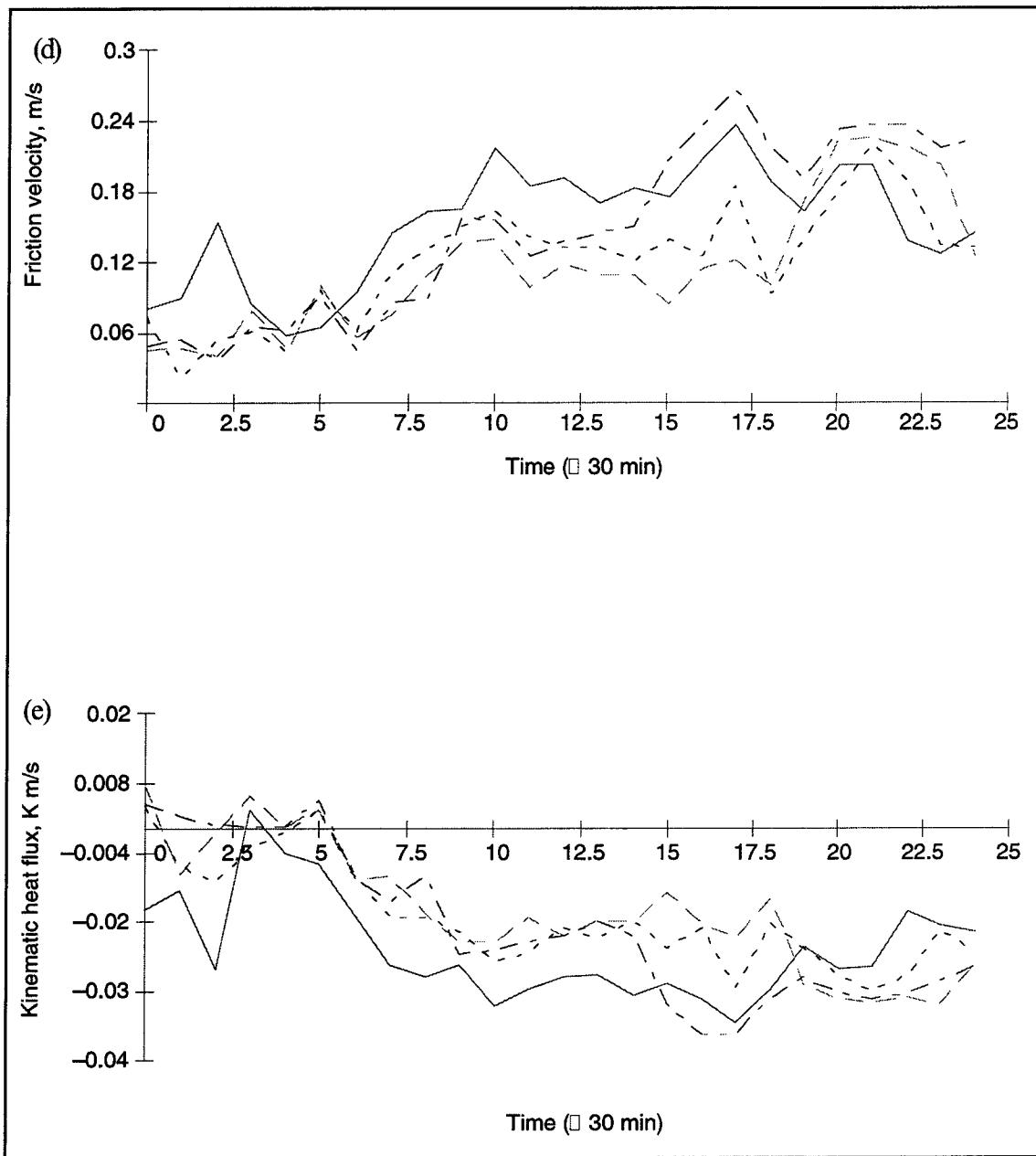
Figure 18 (cont'd). Time series (30-min averages) of (d) friction velocity, and (e) kinematics heat flux at 2 m tower 1 (solid line), tower 2 (dot, tower 3 (dash), and tower 4 (dadot) for IOP5 (11–12 October 1999) started at 1730 CDT.
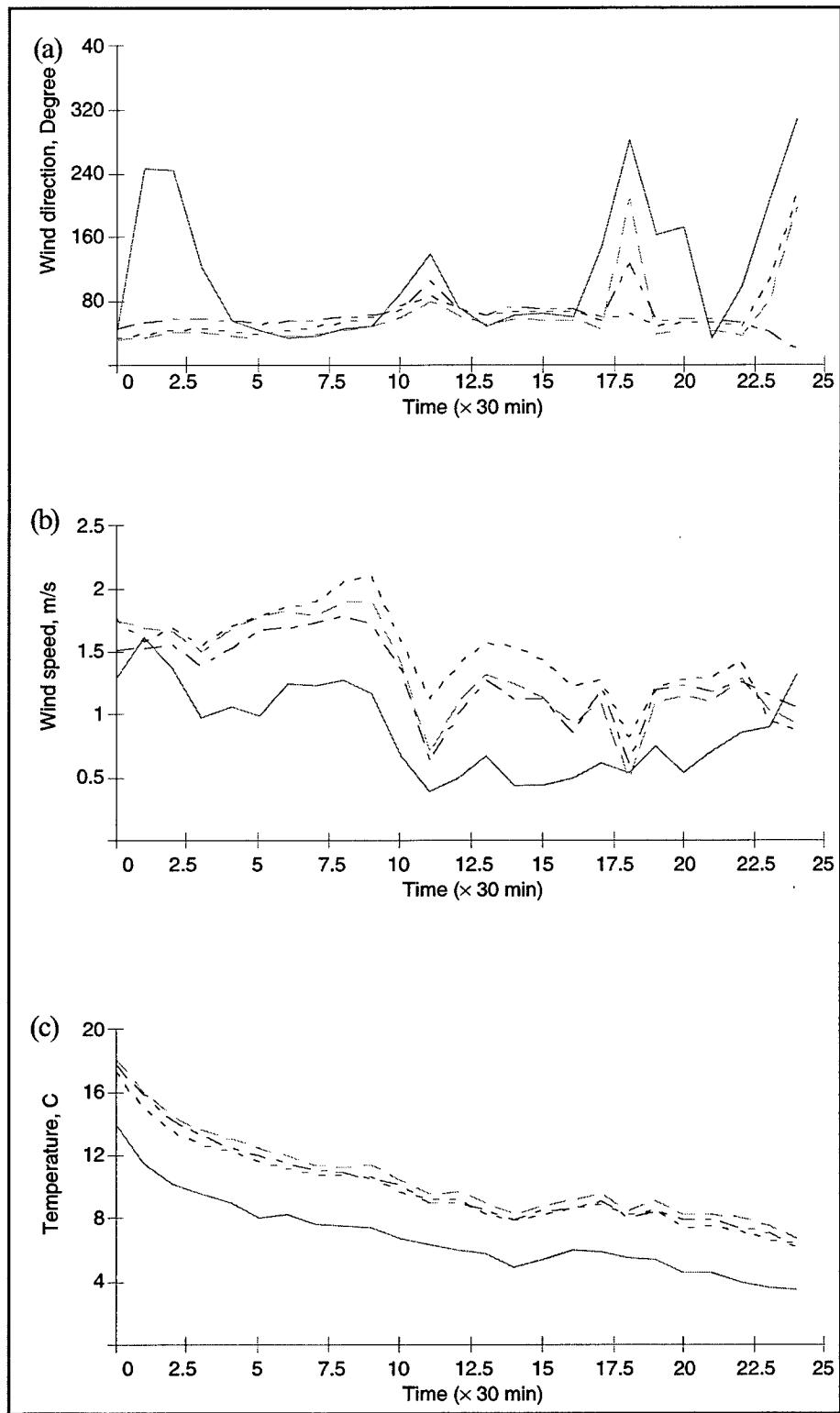
Figure 19. Time series (30-min averages) of (a) wind direction, (b) wind speed, (c) temperature at 2 m tower 1 (solid line), tower 2 (dot), tower 3 (dash), and tower 4 (dadot) for IOP6 (13–14 October 1999) started at 1730 CDt.

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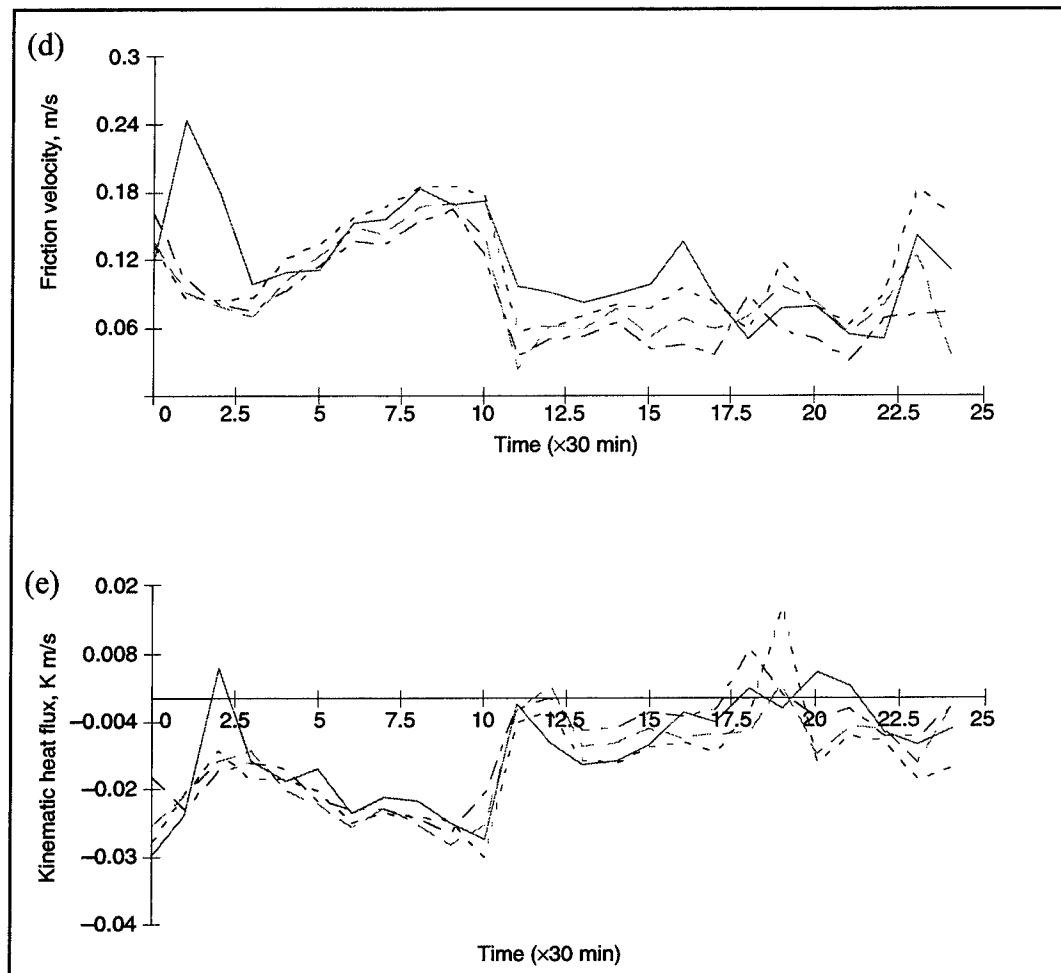
Figure 19 (cont'd). Time series (30-min averages) (d) friction velocity, and (e) kinematic heat flux at 2 m tower 1 (solid line), tower 2 (dot), tower 3 (dash), and tower 4 (dadot) IOP6 (13–14 October 1999) started at 1730 CDT.
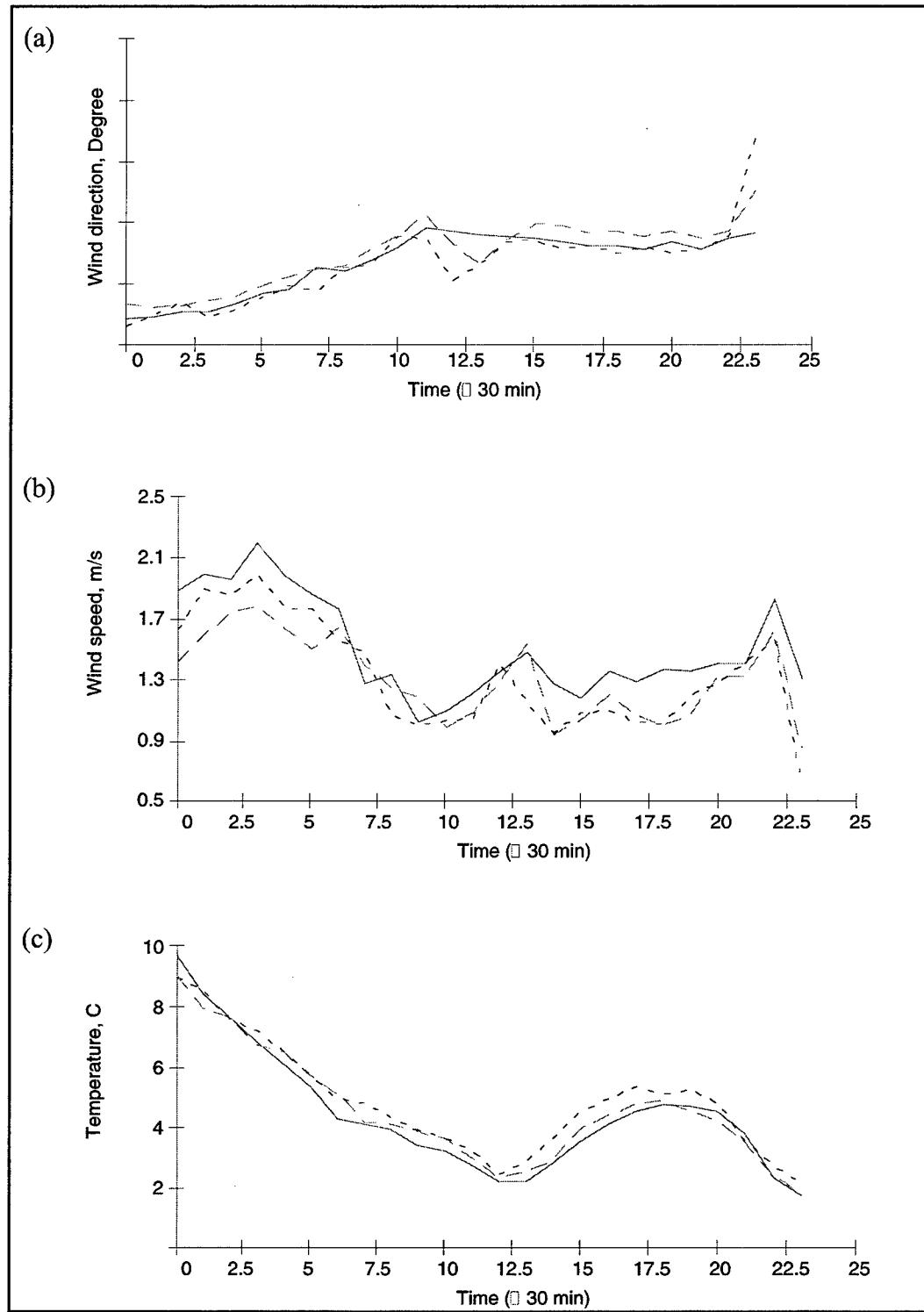
Figure 20. Time series (30-min averages) of (a) wind direction, (b) wind speed,
(c) temperature at 2 m tower 2 (solid line), tower 3 (d), and tower 4 (dash), for
IOP7 (17–18 October 1999) started at 1830 CDT.

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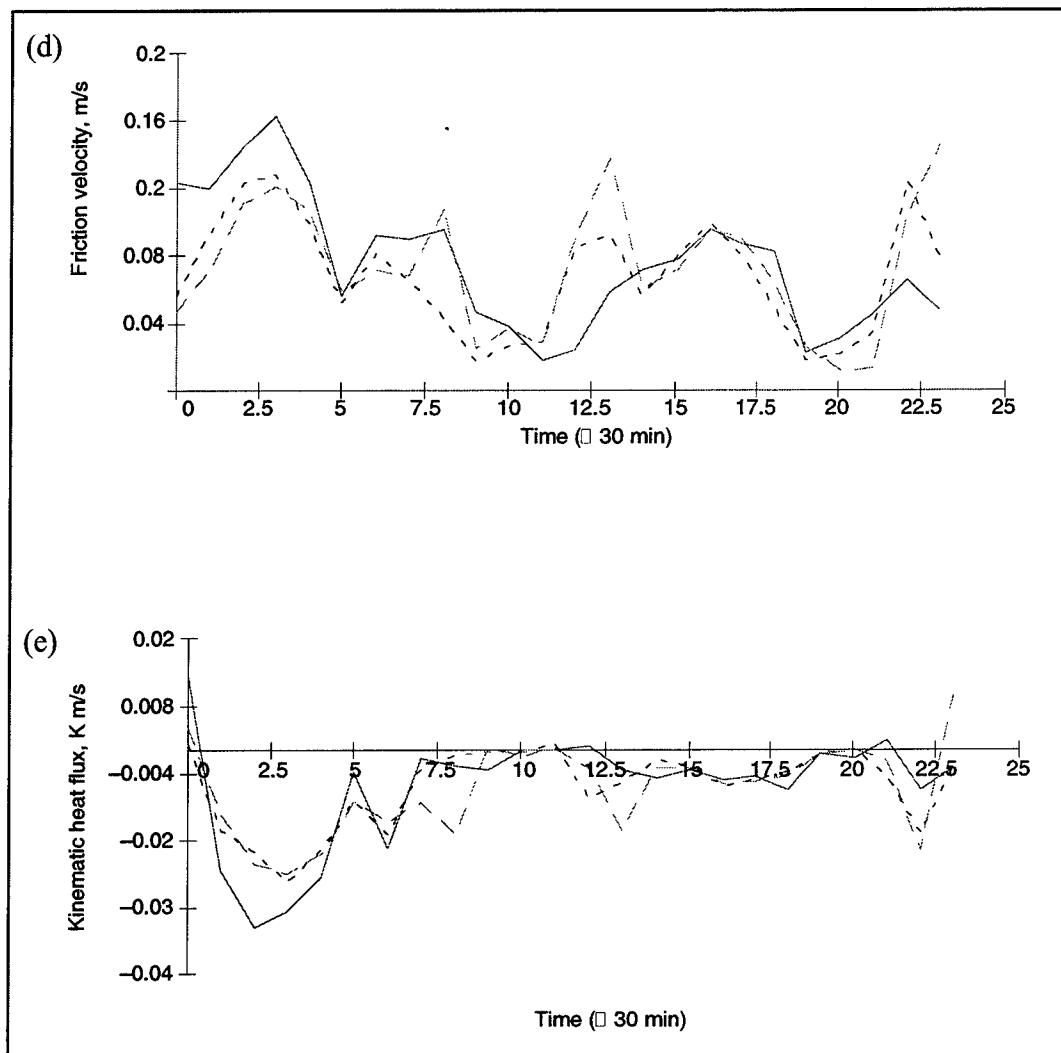
Figure 20 (cont'd). Time series (30-min averages) (d) friction velocity, and (e) kinematics heat flux at 2 m tower 2 (solid line), tower 3 (dot), and tower 4 (dash) for IOP7 (17–18 October 1999) started at 1830 CDT.
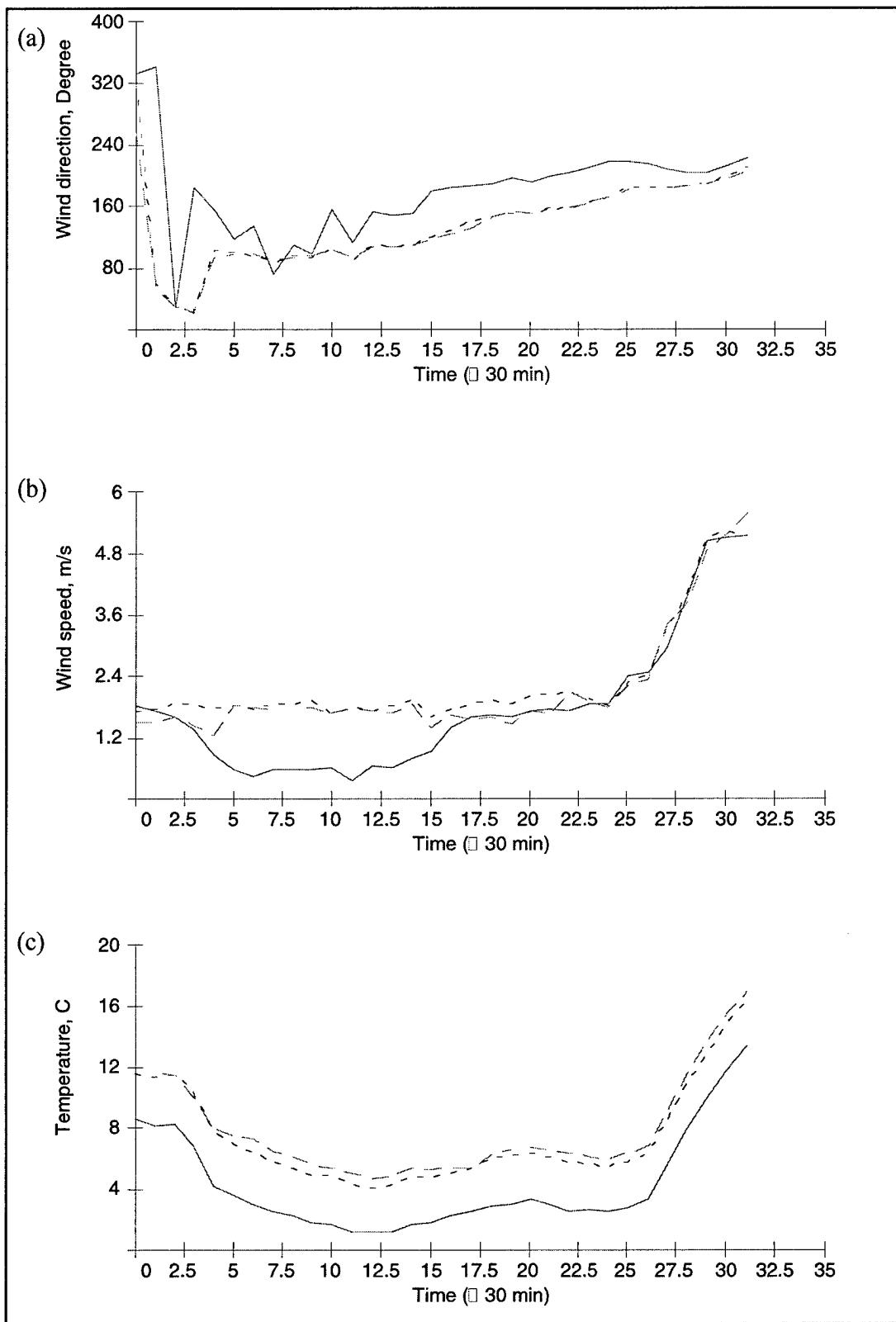
Figure 21. Time series (30-min averages) of (a) wind direction, (b) wind speed, (c) temperature at 2 m tower 1 (solid line), tower 2 (dot), and tower 3 (dash), for IOP8 (19–20 October 1999) started at 1800 CDT.
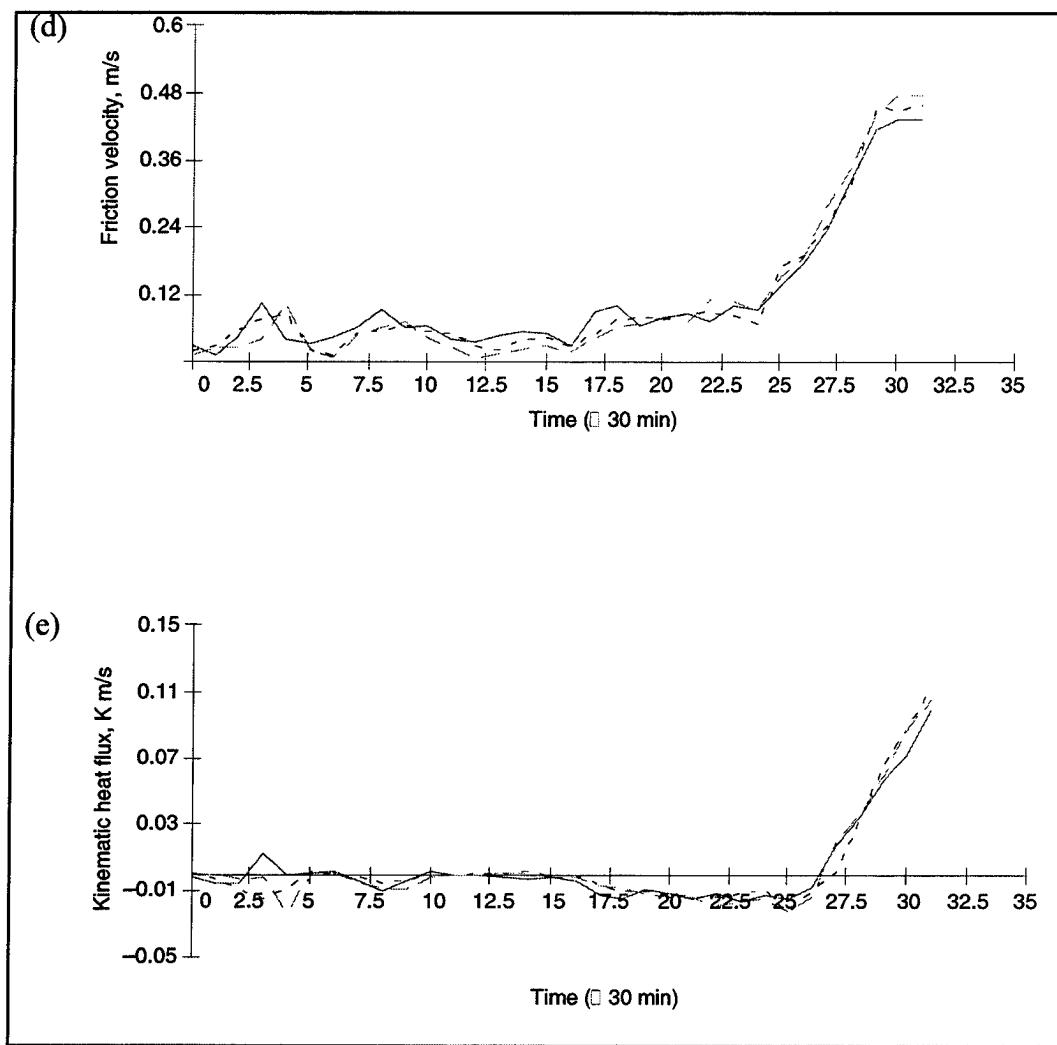
Figure 21 (cont'd). Time series (30-min averages) (d) friction velocity, and (e) kinematics heat flux at 2 m tower 1 (solid line), tower 2 (dot), and tower 3 (dash) for IOP8 (19–20 October 1999) started at 1800 CDT.
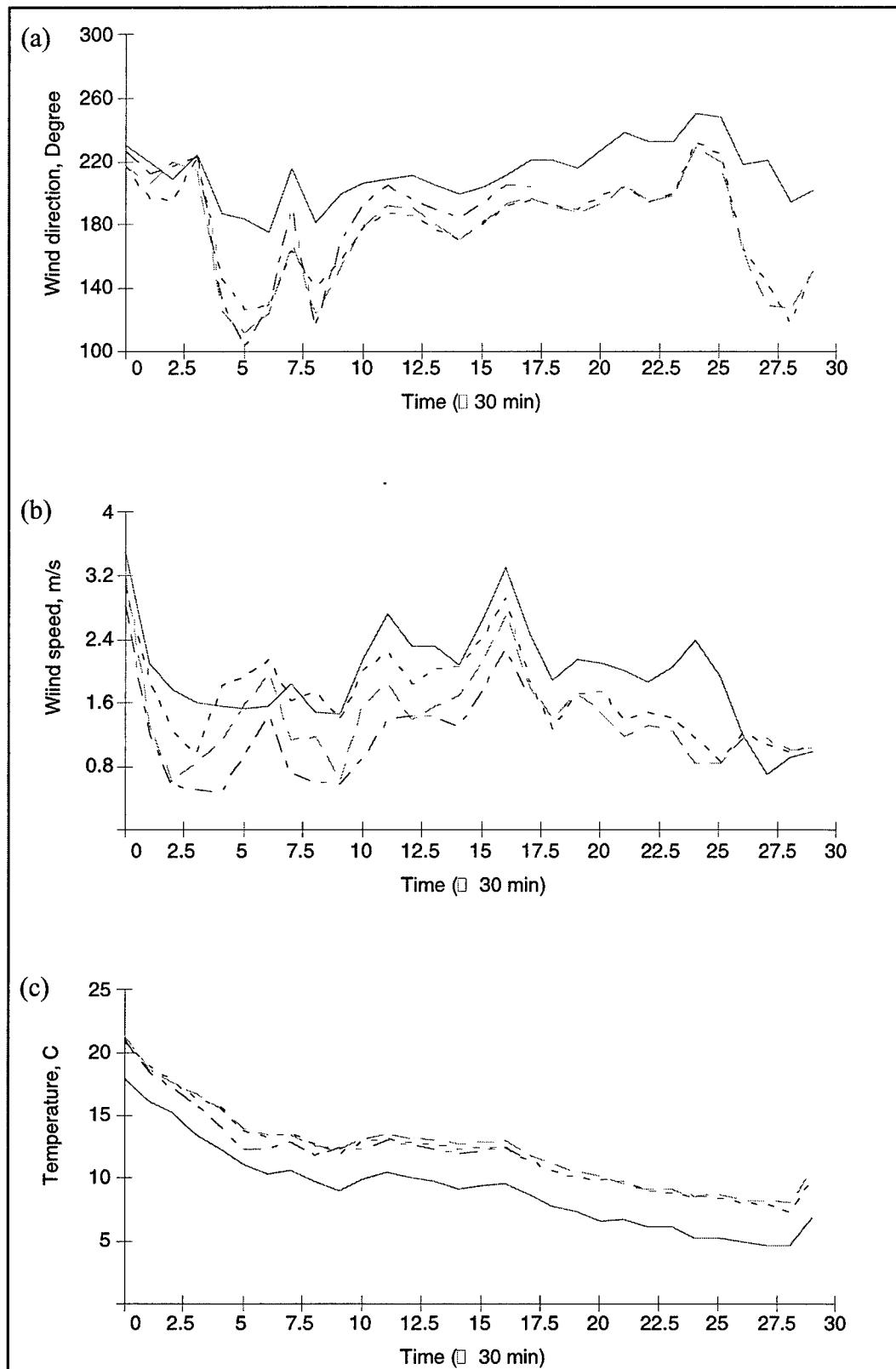
Figure 22. Time series (30-min averages) of (a) wind direction, (b) wind speed, (c) temperature
at 2 m tower 1 (solid line), tower 2 (dot), tower 3 (dash), and tower 4 (dadot) for IOP9
(20–21 October 1999) started at 1700 CDT.

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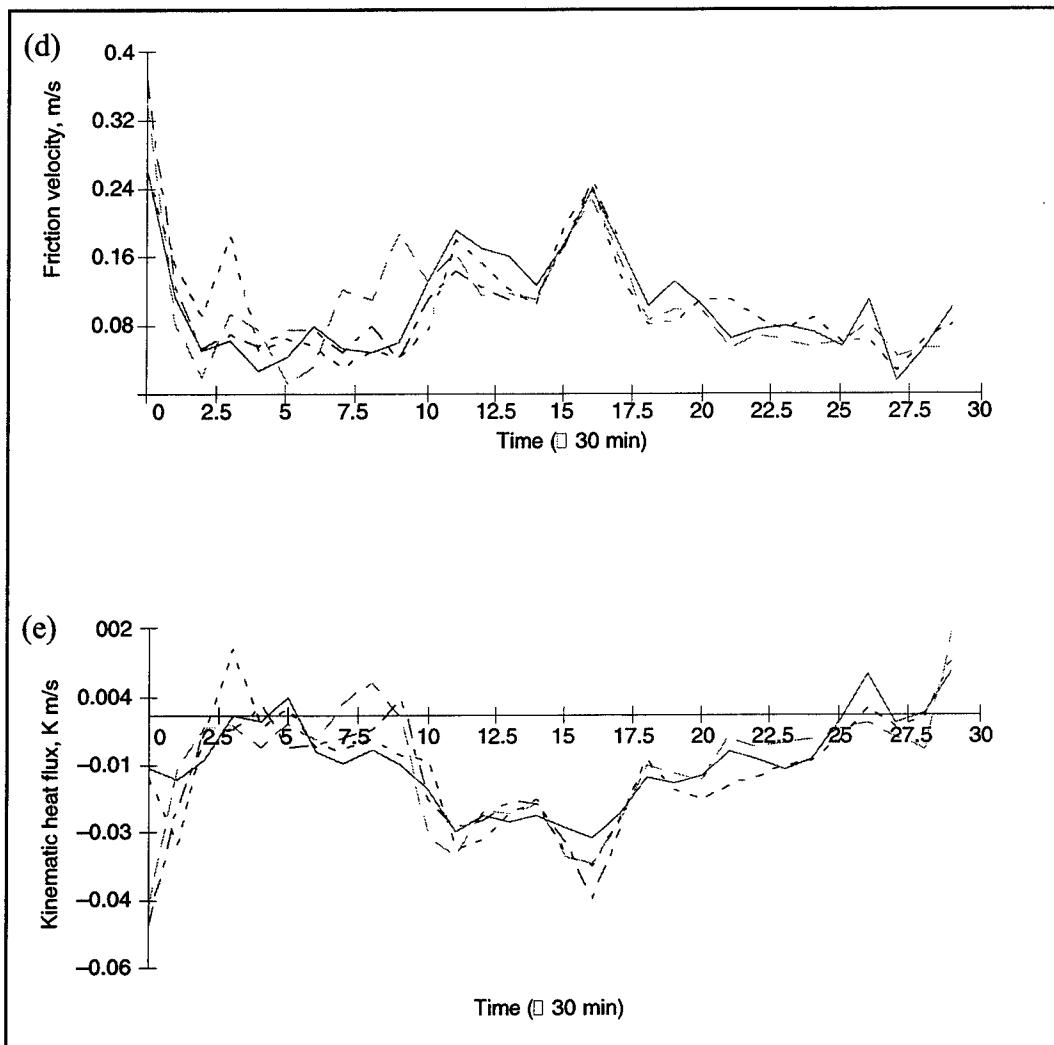
Figure 22 (cont'd). Time series (30-min averages) (d) friction velocity, and (e) kinematics heat flux at 2 m tower 1 (solid line) , tower 2 (dot), tower 3 (dash), and tower 4 (dadot) IOP9 (20–21 October 1999) started at 1700 CDT.

Table 9. Mean values and turbulence statistics from sonic anemometers at 2 m AGL on towers T2 and T3 for IOP3 (9–10 October 1999).

a. Mean values.

Time(CDT)	T2 u (m/s)	T3 u (m/s)	T2 v (m/s)	T3 v (m/s)	T2 w (m/s)	T3 w (m/s)	T2 Spd (m/s)	T3 Spd (m/s)	T2 Wdir (deg)	T3 Wdir (deg)	T2 T (C)	T3 T (C)
1700-1730	1.14	0.95	-0.32	-0.21	-0.05	-0.06	1.20	1.00	284.27	282.37	25.78	26.64
1730-1800	0.51	0.37	0.02	0.04	-0.03	-0.04	0.54	0.42	263.43	261.36	24.48	25.45
1800-1830	0.02	0.02	0.27	0.17	-0.02	-0.03	0.41	0.31	199.14	214.86	23.75	24.05
1830-1900	-1.12	-0.95	0.14	0.05	-0.04	-0.02	1.15	0.99	98.46	91.03	21.98	22.37
1900-1930	-1.04	-1.03	0.46	0.34	-0.03	0.01	1.16	1.09	114.31	107.99	21.53	22.23
1930-2000	-0.98	-1.08	0.75	0.51	-0.01	0.03	1.24	1.21	127.60	114.47	20.36	20.77
2000-2030	-0.34	-0.40	0.82	0.39	0.00	0.00	0.96	0.66	159.63	137.70	20.22	20.19
2030-2100	0.38	0.19	0.68	0.28	0.00	-0.02	0.81	0.37	211.15	215.91	20.11	20.13
2100-2130	-0.09	-0.12	0.99	0.87	0.02	0.03	1.14	1.00	173.59	173.31	19.21	19.64
2130-2200	-0.18	-0.30	0.64	0.51	0.00	0.01	0.81	0.73	164.65	153.65	18.97	19.39
2200-2230	-0.92	-0.94	0.59	0.50	-0.01	0.01	1.16	1.16	124.39	120.07	17.87	18.53
2230-2300	-0.65	-0.80	0.84	0.39	0.00	-0.01	1.17	0.92	147.98	119.34	17.42	17.31
2300-2330	0.56	0.39	0.43	0.34	-0.02	-0.02	0.78	0.58	239.30	232.52	17.87	18.38

b. Turbulence statistics.

Time(CDT)	T2 ustar(m/s)	T3 ustar(m/s)	T2 w'T'(Km/s)	T3 w'T'(Km/s)	T2 u'u'	T3 u'u'	T2 v'v'	T3 v'v'	T2 w'w'	T3 w'w'	T2 T'T'	T3 T'T'
1700-1730	0.07	0.09	0.00	0.00	0.28	0.25	0.04	0.04	0.01	0.02	0.19	0.20
1730-1800	0.02	0.05	0.00	0.00	0.04	0.03	0.04	0.04	0.00	0.00	0.07	0.17
1800-1830	0.05	0.12	0.00	0.00	0.02	0.04	0.09	0.05	0.00	0.00	0.08	0.08
1830-1900	0.08	0.06	0.01	0.01	0.07	0.12	0.03	0.05	0.00	0.00	0.47	0.80
1900-1930	0.05	0.03	0.00	0.00	0.01	0.01	0.05	0.03	0.00	0.00	0.12	0.18
1930-2000	0.01	0.04	0.00	0.00	0.01	0.03	0.02	0.04	0.00	0.00	0.10	0.66
2000-2030	0.07	0.06	0.00	0.00	0.02	0.04	0.15	0.14	0.00	0.00	0.03	0.29
2030-2100	0.07	0.05	0.00	0.00	0.03	0.01	0.05	0.02	0.00	0.00	0.06	0.03
2100-2130	0.09	0.07	0.00	0.00	0.07	0.06	0.27	0.22	0.00	0.00	0.35	0.29
2130-2200	0.07	0.03	0.00	0.00	0.02	0.03	0.24	0.20	0.00	0.00	0.21	0.12
2200-2230	0.09	0.07	0.01	0.01	0.04	0.08	0.15	0.17	0.00	0.00	0.33	0.38
2230-2300	0.05	0.06	0.00	0.00	0.14	0.21	0.20	0.04	0.00	0.00	0.24	0.25
2300-2330	0.08	0.08	0.00	0.00	0.08	0.07	0.10	0.07	0.01	0.01	0.20	0.06

Table 10. Mean values and turbulence statistics from sonic anemometers at 2 m AGL on towers T1–T4 for IOP4 (10–11 October 1999).

a. Mean values.

Tower Time(CDT)	T1 u_t (m/s)	T2 (m/s)	T3 (m/s)	T4 (m/s)	T1 v_t (m/s)	T2 (m/s)	T3 (m/s)	T4 (m/s)	T1 w_t (m/s)	T2 (m/s)	T3 (m/s)	T4 (m/s)	T1 s_t (m/s)	T2 (m/s)	T3 (m/s)	T4 (m/s)	T1 d_t (deg)	T2 (deg)	T3 (deg)	T4 (deg)	T1 T_t (C)	T2 (C)	T3 (C)	T4 (C)
1800-1830	0.69	0.31	0.19	-0.03	-0.24	-0.28	-0.6	-0.56	-0.04	-0.04	-0.02	0.04	0.74	0.45	0.64	0.57	289.02	308.37	340.28	352.16	22.73	25.61	25.61	25.05
1830-1900	0.43	0.16	0.18	-0.34	-1.23	-1.28	-1.16	-1.27	-0.07	-0.08	-0.06	-0.01	1.33	1.31	1.17	1.33	337.47	299.15	340.69	259.91	22.49	25.36	25.12	24.61
1900-1930	0.14	0.06	0.04	-0.35	-1.69	-1.63	-1.35	-1.41	-0.1	-0.11	-0.14	-0.02	1.71	1.64	1.36	1.46	246.42	282.07	246.58	339.17	22.19	25.1	24.93	24.26
1930-2000	-0.22	-0.05	-0.08	-0.55	-2.17	-1.82	-1.51	-1.41	-0.12	-0.12	-0.13	-0.04	2.28	1.84	1.56	1.56	134.74	158.42	165.04	215.13	18.34	22.62	22.77	21.63
2000-2030	-0.82	-1.13	-0.86	-1.33	-1.68	-2.52	-2.43	-1.98	-0.12	-0.15	-0.11	-0.09	1.91	2.82	2.63	2.43	31.89	35.32	37.57	74.38	16.96	21.24	21.73	20.73
2030-2100	-0.78	-1.31	-1.08	-1.48	-1.38	-1.92	-2.1	-1.64	-0.12	-0.13	-0.09	-0.09	1.61	2.35	2.39	2.24	30.86	34.44	27.47	44.55	15.19	19.74	20.73	20.12
2100-2130	-0.92	-1.32	-1.15	-1.51	-1.13	-1.68	-1.91	-1.54	-0.11	-0.13	-0.1	-0.08	1.49	2.16	2.25	2.18	39.83	38.21	30.98	45.29	14.47	18.54	19.57	19.17
2130-2200	-0.82	-1.42	-1.25	-1.62	-0.45	-1.33	-1.61	-1.26	-0.08	-0.11	-0.07	-0.06	1.07	1.96	2.06	2.08	68.12	47.21	37.87	51.86	13.57	17.64	18.68	18.55
2200-2230	-0.81	-1.42	-1.21	-1.37	-0.61	-0.59	-0.84	-0.55	-0.08	-0.1	-0.05	-0.04	1.06	1.6	1.53	1.53	57.21	68.66	57.49	70.89	13.27	16.56	17.48	17.17
2230-2300	-0.99	-1.56	-1.31	-1.44	-0.71	-0.9	-1.02	-0.59	-0.09	-0.11	-0.05	-0.05	1.25	1.83	1.68	1.58	54.56	60.91	52.58	68.15	13.66	16.37	17.09	16.58
2300-2330	-1.2	-1.71	-1.51	-1.63	-0.75	-1.13	-1.31	-0.7	-0.1	-0.11	-0.05	-0.04	1.46	2.07	2.02	1.79	57.58	56.58	49.18	66.73	14	16.89	17.68	16.96
2330-2400	-1.56	-1.91	-1.56	-1.8	-1.12	-1.06	-1.19	-0.73	-0.09	-0.12	-0.05	-0.05	1.96	2.21	1.99	1.97	54.15	60.91	52.56	67.91	14.52	17.29	17.82	17.25
0000-0030	-2.1	-2.11	-1.75	-1.97	-1.27	-1.42	-1.62	-1.02	-0.11	-0.12	-0.07	-0.08	2.51	2.58	2.41	2.25	58.62	56.04	47.14	62.56	14.82	17.62	18.2	17.46
0030-0100	-3.09	-2.62	-2.29	-2.66	-0.93	-1.56	-1.82	-1.11	-0.1	-0.14	-0.08	-0.05	3.29	3.1	2.97	2.93	72.63	58.98	51.21	66.91	15.1	17.88	18.49	17.79
0100-0130	-3.21	-3.69	-3.2	-3.68	-1.11	-1.41	-1.72	-0.85	-0.1	-0.16	-0.06	-0.03	3.46	4.01	3.68	3.83	70.74	69	61.47	76.62	14.77	18.28	18.81	18.33
0130-0200	-3.19	-3.75	-3.37	-3.85	-0.81	-1.51	-1.89	-1.04	-0.1	-0.15	-0.08	-0.04	3.36	4.1	3.91	4.03	75.28	67.99	60.48	74.81	14.46	18.03	18.59	18.09
0200-0230	-3.55	-3.67	-3.23	-3.72	-0.85	-1.35	-1.6	-0.77	-0.09	-0.16	-0.04	-0.01	3.72	3.96	3.65	3.85	76.24	69.83	63.36	78.29	14.26	17.63	18.14	17.69
0230-0300	-2.9	-4.04	-3.62	-3.75	-0.59	-1.28	-1.46	-0.65	-0.08	-0.17	-0.05	0	3.05	4.29	4.04	3.87	77.8	72.42	65.29	80.19	13.75	17.55	18.1	17.51
0300-0330	-2.98	-3.68	-3.35	-3.7	-0.25	-1.22	-1.62	-0.82	-0.09	-0.16	-0.05	-0.03	3.06	3.94	3.78	3.85	85.38	71.81	63.92	77.4	13.3	17.03	17.56	17.04
0330-0400	-3.2	-3.66	-3.55	-3.65	-0.45	-0.79	-1.3	-0.4	-0.09	-0.12	-0.04	-0	3.32	3.81	3.83	3.73	81.79	78.06	69.68	83.56	13.1	16.66	17.25	16.67
0400-0430	-2.81	-3.69	-3.62	-3.87	-0.52	-0.78	-1.29	-0.36	-0.09	-0.15	-0.03	0.01	2.95	3.83	3.9	3.95	80.51	78.31	70.46	84.65	12.74	16.34	17	16.5
0430-0500	-2.5	-3.87	-3.64	-3.91	-0.47	1.11	-1.63	-0.7	-0.09	-0.14	-0.07	0.01	2.64	4.08	4.04	4.03	80.02	74.13	65.73	80	12.41	16.11	16.67	16.19
0500-0530	-2.43	-3.6	-3.45	-3.71	-0.59	0.98	-1.41	-0.59	-0.09	-0.16	-0.03	0.01	2.62	3.78	3.78	3.81	78.97	75.02	67.65	81.02	12.17	15.73	16.32	15.85
0530-0600	-2.5	-3.32	-3.16	-3.34	-0.48	-0.9	-1.34	-0.48	-0.09	-0.14	-0.06	0.01	2.64	3.5	3.49	3.43	80.5	74.88	66.79	81.82	11.92	15.46	16.05	15.5
0600-0630	-2.81	-3.27	-3.14	-3.36	-0.53	-0.99	-1.41	-0.51	-0.08	-0.16	-0.06	-0	2.96	3.47	3.49	3.45	80.87	73.12	65.56	81.24	11.93	15.19	15.76	15.26

b. Turbulence statistics.

Tower Time(CDT)	T1 ustar (m/s)	T2 (m/s)	T3 (m/s)	T4 (m/s)	T1 H (Km/s)	T2 (Km/s)	T3 (Km/s)	T4 (Km/s)	T1 $u'u'_t$ (m²/s²)	T2 (m²/s²)	T3 (m²/s²)	T4 (m²/s²)	T1 $v'v'_t$ (m²/s²)	T2 (m²/s²)	T3 (m²/s²)	T4 (m²/s²)	T1 $w'w'_t$ (m²/s²)	T2 (m²/s²)	T3 (m²/s²)	T4 (m²/s²)	T1 TT_t (C²)	T2 (C²)	T3 (C²)	T4 (C²)
1800-1830	0.029	0.039	0.057	0.018	-0.002	-0.002	0.000	0.001	0.012	0.011	0.03	0.013	0.013	0.033	0.007	0.006	0.001	0.000	0.001	0.000	0.126	0.098	0.064	0.056
1830-1900	0.030	0.020	0.058	0.099	-0.001	-0.002	0.002	0.010	0.128	0.16	0.049	0.092	0.089	0.037	0.009	0.040	0.000	0.001	0.002	0.001	0.106	0.225	0.307	0.262
1900-1930	0.033	0.022	0.024	0.040	0.003	-0.001	0.000	0.001	0.016	0.026	0.021	0.019	0.037	0.02	0.018	0.010	0.001	0.001	0.000	0.000	0.770	0.138	0.158	0.195
1930-2000	0.278	0.193	0.162	0.124	-0.025	0.020	0.013	0.022	0.77	0.342	0.242	0.167	0.445	0.066	0.159	0.143	0.050	0.016	0.010	0.008	0.363	2.113	2.092	2.034
2000-2030	0.209	0.303	0.246	0.235	-0.042	-0.062	-0.049	-0.044	0.202	0.46	0.31	0.276	0.134	0.371	0.268	0.232	0.059	0.094	0.077	0.068	0.623	0.328	0.159	0.165
2030-2100	0.176	0.216	0.212	0.218	-0.028	-0.029	-0.032	-0.043	0.102	0.165	0.166	0.207	0.077	0.133	0.130	0.130	0.047	0.063	0.064	0.064	0.145	0.132	0.117	0.331
2100-2130	0.172	0.191	0.194	0.211	-0.026	-0.029	-0.032	-0.034	0.107	0.127	0.146	0.185	0.092	0.083	0.086	0.099	0.046	0.052	0.057	0.058	0.096	0.195	0.210	0.149
2130-2200	0.196	0.179	0.181	0.210	-0.040	-0.030	-0.031	-0.033	0.201	0.116	0.13	0.196	0.192	0.098	0.096	0.130	0.027	0.046	0.049	0.058	0.313	0.133	0.099	0.119
2200-2230	0.137	0.146	0.147	0.176	-0.024	-0.028	-0.029	-0.035	0.115	0.079	0.129	0.206	0.087	0.182	0.161	0.142	0.023	0.022	0.023	0.032	0.190	0.254	0.448	0.484
2230-2300	0.155	0.143	0.129	0.140	-0.023	-0.024	-0.022	-0.023	0.092	0.105	0.109	0.118	0.081	0.117	0.078	0.067	0.039	0.028	0.024	0.025	0.058	0.171	0.201	0.138
2300-2330	0.177	0.173	0.184	0.183	-0.027	-0.025	-0.029	-0.027	0.128	0.123	0.139	0.174	0.098	0.093	0.088	0.077	0.045	0.049	0.051	0.042	0.124	0.062	0.086	0.144
2330-2400	0.241	0.215	0.184	0.186	-0.039	-0.036	-0.030	-0.032	0.312	0.174	0.15	0.183	0.152	0.11	0.092	0.090	0.079	0.062	0.052	0.049	0.117	0.138	0.258	0.179
0000-0030	0.300	0.254	0.245	0.221	-0.040	-0.035	-0.040	-0.036	0.401	0.282	0.244	0.212	0.289	0.166	0.137	0.113	0.126	0.088	0.080	0.062	0.064	0.085	0.090	0.083
0030-0100	0.415	0.337	0.313	0.308	-0.047	-0.047	-0.044	-0.050	0.998	0.466	0.472	0.613	0.392	0.294	0.288	0.244	0.196	0.145	0.126	0.110	0.057	0.074	0.096	0.125
0100-0130	0.387	0.456	0.371	0.389	-0.041	-0.057	-0.046	-0.063	0.741	0.933	0.698	1.017	0.447	0.454	0.358	0.396	0.209	0.231	0.189	0.170	0.052	0.065	0.067	0.108
0130-0200	0.412	0.478	0.428	0.419	-0.041	-0.052	-0.053	-0.065	0.883	0.963	0.817	0.995	0.454	0.487	0.402	0.408	0.210	0.253	0.214	0.191	0.042	0.070	0.079	0.117
0200-0230	0.480	0.458	0.373	0.397	0.044	-0.050	-0.040	-0.061	1.265	0.904	0.687	1.043	0.543	0.451	0.377	0.417	0.240	0.237	0.188	0.177	0.056	0.051	0.049	0.087
0230-0300	0.433	0.513	0.400	0.377	-0.036	-0.054	-0.041	-0.054	1.35	1.16	0.856	1.053	0.462	0.485	0.458	0.457	0.197	0.281	0.221	0.181	0.061	0.052	0.049	0.081
0300-0330	0.455	0.452	0.394	0.379	-0.037	-0.043	-0.041	-0.054	1.103	0.917	0.849	0.959	0.398	0.452	0.422	0.452	0.189	0.241	0.209	0.175	0.042	0.066	0.078	0.103
0330-0400	0.489	0.490	0.395	0.396	-0.039	-0.051	-0.049	-0.058	1.034	1.034	0.881	1.141	0.461	0.472	0.408	0.434	0.217	0.259	0.210	0.181	0.036	0.063	0.043	0.073
0400-0430	0.463	0.487	0.443	0.405	-0.034	-0.048	-0.041	-0.057	1.294	1.068	1.006	1.141	0.41	0.436	0.435	0.467	0.187	0.245	0.218	0.196	0.045	0.049	0.050	0.077
0430-0500	0.458	0.498	0.439	0.410	-0.032	-0.042	-0.041	-0.058	1.478	1.112	0.917	1.108	0.39	0.495	0.448	0.471	0.173	0.262	0.238	0.202	0.037	0.042	0.050	0.077
0500-0530	0.444	0.441	0.400	0.389	-0.032	-0.040	-0.038	-0.054	1.239	0.85	0.87	1.093	0.433	0.427	0.429	0.461	0.172	0.225	0.211	0.182	0.038	0.045	0.047	0.074
0530-0600	0.421	0.430	0.365	0.363	-0.026	-0.044	-0.037	-0.050	1.224	0.776	0.734	0.953	0.378	0.37	0.381	0.355	0.157	0.206	0.174	0.152	0.038	0.043	0.044	0.073
0600-0630	0.480	0.399	0.381	0.352	-0.016	-0.039	-0.039	-0.050	1.487	0.749	0.773	0.912	0.456	0.36	0.369	0.379	0.191	0.184	0.184	0.149	0.027	0.047	0.046	0.069

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Table 11. Mean values and turbulence statistics from sonic anemometers at 2 m AGL on towers T1–T4 for IOP5 (11–12 October 1999).

a. Mean values.

Tower Time(CDT)	T1 u m/s	T2 u m/s	T3 u m/s	T4 u m/s	T1 v m/s	T2 v m/s	T3 v m/s	T4 v m/s	T1 w m/s	T2 w m/s	T3 w m/s	T4 w m/s	T1 s m/s	T2 s m/s	T3 s m/s	T4 s m/s	T1 d deg	T2 d deg	T3 d deg	T4 d deg	T1 T C	T2 T C	T3 T C	T4 T C
1730-1800	-0.42	1.00	-0.92	0.55	1.16	1.22	1.04	1.19	-0.04	0.02	0.10	0.06	1.28	1.62	1.42	1.35	160.72	140.40	138.36	155.18	21.66	24.92	25.44	24.61
1800-1830	0.29	1.08	-0.96	0.64	1.16	1.05	0.87	0.97	-0.03	0.01	0.08	0.05	1.25	1.52	1.31	1.18	167.07	134.50	132.10	146.09	19.88	23.01	23.24	22.17
1830-1900	-0.51	-1.14	-1.01	-0.81	1.32	0.72	0.47	0.72	-0.03	-0.00	0.06	0.02	1.49	1.37	1.12	1.09	159.87	121.47	114.48	131.49	18.99	21.55	22.10	20.86
1900-1930	0.25	-0.79	-0.59	-0.06	1.02	1.17	1.12	0.88	-0.05	0.02	0.09	0.06	1.21	1.47	1.29	0.92	196.46	146.05	151.90	178.13	17.44	20.85	21.25	20.28
1930-2000	-0.14	0.85	-0.67	-0.38	1.13	1.28	1.12	1.04	-0.05	0.02	0.09	0.05	1.18	1.57	1.34	1.15	172.83	147.18	149.09	160.38	16.19	19.78	20.17	19.27
2000-2030	-0.41	-1.11	-1.07	-0.91	1.02	0.85	0.68	0.79	-0.06	-0.00	0.07	0.02	1.15	1.47	1.36	1.28	156.83	127.22	123.08	132.20	15.64	19.11	19.51	18.58
2030-2100	-0.83	-1.45	-1.34	-0.99	1.15	1.05	0.83	1.10	-0.06	-0.00	0.07	0.02	1.44	1.83	1.60	1.50	143.09	125.19	121.64	137.69	15.54	18.50	18.80	17.81
2100-2130	-0.66	-1.45	-1.13	-0.75	1.53	1.60	1.36	1.49	-0.04	0.03	0.11	0.04	1.69	2.17	1.79	1.68	156.56	137.71	140.17	152.86	15.70	18.83	19.15	18.02
2130-2200	-0.56	-1.34	-1.11	-0.62	1.79	1.84	1.67	1.70	-0.04	0.05	0.13	0.07	1.90	2.30	2.04	1.84	162.24	143.70	145.87	159.39	15.83	19.19	19.61	18.44
2200-2230	-0.58	-1.36	-1.20	-0.55	1.94	2.01	2.02	2.20	-0.05	0.06	0.16	0.10	2.05	2.45	2.38	2.29	163.41	145.63	149.19	165.75	16.20	19.61	20.19	19.42
2230-2300	-0.77	-1.46	-1.36	-0.70	2.02	1.87	1.82	1.99	-0.05	0.06	0.14	0.09	2.19	2.41	2.30	2.13	159.00	141.92	143.20	160.29	16.45	19.60	20.19	19.28
2300-2330	-0.51	-1.23	-1.11	-0.52	1.87	1.86	1.84	1.93	-0.04	0.05	0.14	0.08	1.98	2.26	2.18	2.02	164.91	146.79	148.87	164.87	16.17	19.45	20.04	19.16
2330-2400	-0.21	-0.88	-0.81	-0.24	1.98	2.12	2.11	2.14	-0.05	0.07	0.16	0.10	2.02	2.32	2.28	2.17	174.34	157.29	158.92	173.44	15.84	19.29	19.99	19.24
0000-0030	-0.12	-0.86	-0.81	-0.20	1.99	2.13	2.14	2.15	-0.03	0.07	0.16	0.10	2.01	2.32	2.30	2.18	176.72	157.95	159.14	174.61	15.71	19.13	19.71	18.96
0030-0100	0.03	-0.75	-0.69	0.06	2.11	2.24	2.25	2.17	-0.03	0.09	0.17	0.11	2.14	2.39	2.38	2.19	179.22	161.19	162.65	178.05	15.81	19.20	19.85	19.09
0100-0130	0.31	-0.41	-0.36	0.23	2.31	2.43	2.37	2.21	-0.02	0.09	0.18	0.14	2.37	2.50	2.43	2.25	187.98	170.42	171.28	185.75	16.33	19.56	20.17	19.44
0130-0200	0.60	-0.10	-0.15	0.40	2.57	2.78	2.65	2.41	-0.01	0.12	0.18	0.15	2.68	2.81	2.69	2.47	193.49	177.71	176.59	189.10	16.58	19.80	20.38	19.61
0200-0230	0.48	-0.24	-0.25	0.41	2.92	3.07	3.00	2.74	-0.02	0.12	0.19	0.17	3.00	3.12	3.05	2.80	189.64	175.42	175.27	188.36	16.93	20.13	20.74	20.02
0230-0300	0.57	-0.11	-0.16	0.36	2.28	2.45	2.36	2.17	-0.02	0.09	0.17	0.13	2.39	2.48	2.39	2.22	194.30	177.26	175.98	189.27	16.49	19.70	20.29	19.55
0300-0330	0.77	0.14	0.12	0.55	1.94	2.09	2.08	1.81	-0.03	0.08	0.14	0.12	2.15	2.12	2.11	1.91	202.43	183.93	183.53	197.05	16.04	19.23	19.80	19.03
0330-0400	0.98	0.18	0.15	0.65	2.48	2.53	2.58	2.26	-0.03	0.10	0.17	0.14	2.70	2.57	2.62	2.38	201.63	183.94	183.03	195.83	15.86	19.01	19.59	18.84
0400-0430	1.12	0.35	0.29	0.70	2.36	2.55	2.54	2.30	-0.03	0.09	0.15	0.14	2.66	2.60	2.59	2.43	205.98	187.86	186.29	197.01	15.67	18.86	19.40	18.76
0430-0500	1.09	0.35	0.26	0.73	2.01	2.45	2.56	2.23	-0.02	0.09	0.17	0.13	2.33	2.51	2.61	2.38	208.47	187.93	185.60	198.55	15.41	18.66	19.28	18.64
0500-0530	0.63	-0.03	0.01	0.59	1.91	2.41	2.44	2.02	-0.03	0.08	0.15	0.14	2.08	2.44	2.48	2.13	198.22	179.11	179.99	196.31	14.85	18.38	19.03	18.35
0530-0600	0.60	-0.14	-0.16	0.50	2.22	2.49	2.44	2.15	-0.02	0.10	0.17	0.14	2.35	2.53	2.48	2.24	195.03	176.97	176.38	193.25	14.41	17.89	18.50	17.92

b. Turbulence statistics.

Tower Time(CDT)	T1 u_* m/s	T2 u_* m/s	T3 u_* m/s	T4 u_* m/s	T1 $\overline{wT}$ Km/s	T2 $\overline{wT}$ Km/s	T3 $\overline{wT}$ Km/s	T4 $\overline{wT}$ Km/s	T1 $\overline{u'u'}$ m²/s²	T2 $\overline{u'u'}$ m²/s²	T3 $\overline{u'u'}$ m²/s²	T4 $\overline{u'u'}$ m²/s²	T1 $\overline{v'v'}$ m²/s²	T2 $\overline{v'v'}$ m²/s²	T3 $\overline{v'v'}$ m²/s²	T4 $\overline{v'v'}$ m²/s²	T1 $\overline{w'w'}$ m²/s²	T2 $\overline{w'w'}$ m²/s²	T3 $\overline{w'w'}$ m²/s²	T4 $\overline{w'w'}$ m²/s²	T1 $\overline{TT}$ C²	T2 $\overline{TT}$ C²	T3 $\overline{TT}$ C²	T4 $\overline{TT}$ C²
1730-1800	0.081	0.074	0.044	0.048	-0.014	0.004	0.007	0.004	0.052	0.040	0.029	0.033	0.106	0.126	0.101	0.086	0.009	0.009	0.007	0.006	0.482	0.620	0.672	0.650
1800-1830	0.089	0.022	0.046	0.054	-0.011	-0.006	-0.008	0.002	0.086	0.088	0.033	0.023	0.138	0.045	0.041	0.040	0.011	0.007	0.005	0.002	0.192	0.204	0.388	0.304
1830-1900	0.154	0.053	0.039	0.035	-0.024	-0.009	-0.001	0.001	0.163	0.062	0.023	0.008	0.196	0.061	0.017	0.020	0.034	0.012	0.003	0.001	0.233	0.269	0.082	0.078
1900-1930	0.084	0.061	0.079	0.065	0.003	-0.003	0.006	0.000	0.059	0.129	0.058	0.074	0.374	0.143	0.053	0.060	0.008	0.009	0.006	0.003	0.492	0.295	0.202	0.129
1930-2000	0.058	0.045	0.044	0.063	-0.004	-0.001	0.000	0.000	0.031	0.039	0.034	0.055	0.089	0.108	0.091	0.084	0.005	0.004	0.004	0.003	0.191	0.157	0.197	0.114
2000-2030	0.064	0.096	0.100	0.091	-0.006	0.003	0.003	0.005	0.050	0.028	0.022	0.018	0.115	0.198	0.228	0.188	0.005	0.005	0.004	0.002	0.079	0.191	0.141	0.196
2030-2100	0.095	0.061	0.056	0.045	-0.015	0.008	-0.008	-0.008	0.083	0.045	0.026	0.020	0.056	0.114	0.067	0.069	0.016	0.008	0.006	0.005	0.093	0.107	0.096	0.108
2100-2130	0.145	0.112	0.075	0.086	-0.023	-0.015	-0.008	-0.012	0.104	0.083	0.087	0.064	0.066	0.065	0.059	0.041	0.033	0.027	0.023	0.019	0.086	0.076	0.140	0.144
2130-2200	0.162	0.131	0.110	0.089	-0.026	-0.015	-0.015	-0.008	0.166	0.150	0.147	0.116	0.091	0.115	0.111	0.110	0.042	0.038	0.035	0.029	0.098	0.105	0.115	0.213
2200-2230	0.165	0.150	0.136	0.157	-0.024	-0.018	-0.020	-0.022	0.182	0.193	0.175	0.202	0.096	0.109	0.113	0.094	0.049	0.048	0.049	0.055	0.139	0.081	0.095	0.126
2230-2300	0.216	0.162	0.139	0.155	-0.031	-0.023	0.020	0.021	0.261	0.193	0.204	0.188	0.138	0.145	0.139	0.110	0.065	0.054	0.052	0.054	0.098	0.096	0.101	0.117
2300-2330	0.183	0.141	0.099	0.125	-0.028	-0.021	-0.015	-0.020	0.227	0.169	0.169	0.149	0.160	0.168	0.146	0.104	0.054	0.044	0.040	0.043	0.135	0.089	0.094	0.102
2330-2400	0.191	0.132	0.118	0.137	-0.026	-0.017	-0.019	-0.019	0.213	0.174	0.174	0.187	0.100	0.094	0.101	0.083	0.053	0.043	0.043	0.050	0.093	0.097	0.093	0.106
0000-0030	0.170	0.131	0.108	0.145	-0.025	-0.019	-0.016	-0.016	0.187	0.181	0.179	0.174	0.092	0.092	0.088	0.079	0.047	0.043	0.042	0.053	0.105	0.099	0.099	0.114
0030-0100	0.182	0.122	0.108	0.150	-0.029	-0.016	-0.016	-0.019	0.241	0.228	0.215	0.228	0.112	0.126	0.119	0.101	0.058	0.051	0.049	0.057	0.135	0.118	0.136	0.157
0100-0130	0.175	0.139	0.084	0.208	-0.027	-0.021	-0.011	-0.030	0.300	0.281	0.296	0.266	0.201	0.172	0.156	0.114	0.071	0.056	0.054	0.073	0.143	0.110	0.121	0.125
0130-0200	0.207	0.125	0.114	0.236	-0.029	-0.017	-0.016	-0.036	0.392	0.324	0.364	0.350	0.189	0.164	0.153	0.110	0.091	0.070	0.069	0.089	0.136	0.127	0.152	0.198
0200-0230	0.236	0.184	0.122	0.266	-0.034	-0.027	-0.019	-0.036	0.490	0.468	0.418	0.445	0.275	0.218	0.215	0.156	0.119	0.090	0.089	0.108	0.096	0.098	0.097	0.120
0230-0300	0.187	0.093	0.101	0.215	-0.028	-0.017	-0.012	-0.029	0.330	0.309	0.307	0.284	0.174	0.143	0.129	0.093	0.072	0.056	0.055	0.068	0.123	0.139	0.144	0.145
0300-0330	0.162	0.139	0.171	0.191	-0.020	-0.021	-0.027	-0.026	0.316	0.220	0.221	0.182	0.225	0.115	0.111	0.082	0.055	0.049	0.050	0.054	0.105	0.122	0.130	0.139
0330-0400	0.201	0.180	0.223	0.232	-0.024	-0.025	-0.030	-0.029	0.429	0.311	0.370	0.361	0.172	0.137	0.154	0.117	0.076	0.062	0.071	0.078	0.075	0.082	0.090	0.089
0400-0430	0.202	0.220	0.225	0.235	-0.024	-0.028	-0.030	-0.030	0.400	0.339	0.336	0.342	0.237	0.157	0.183	0.124	0.075	0.070	0.073	0.080	0.070	0.080	0.080	0.092
0430-0500	0.137	0.188	0.217	0.235	-0.014	-0.025	-0.029	-0.028	0.359	0.339	0.319	0.371	0.228	0.149	0.181	0.143	0.052	0.061	0.075	0.082	0.085	0.096	0.085	0.104
0500-0530	0.127	0.133	0.201	0.216	-0.017	-0.018	-0.030	-0.026	0.332	0.258	0.302	0.240	0.250	0.155	0.179	0.115	0.045	0.054	0.065	0.072	0.116	0.124	0.127	0.101
0530-0600	0.144	0.133	0.125	0.223	-0.018	-0.021	-0.023	-0.024	0.203	0.261	0.292	0.317	0.195	0.149	0.164	0.139	0.055	0.050	0.061	0.074	0.103	0.093	0.106	0.111

Table 12. Mean values and turbulence statistics from sonic anemometers at 2 m AGL on towers T1–T4 for IOP6 (13–14 October 1999).

a. Mean values.

Tower Time(CDT)	T1 m/s u	T2 m/s u	T3 m/s u	T4 m/s u	T1 m/s v	T2 m/s v	T3 m/s v	T4 m/s v	T1 m/s w	T2 m/s w	T3 m/s w	T4 m/s w	T1 s s	T2 s s	T3 s s	T4 s s	T1 deg d	T2 deg d	T3 deg d	T4 deg d	T1 C T	T2 C T	T3 C T	T4 C T
1730-1800	-0.38	-1.05	-0.94	-1.11	-1.20	-1.41	-1.47	-1.01	-0.10	-0.12	-0.09	-0.05	1.28	1.78	1.76	1.52	40.58	36.75	32.65	47.60	13.93	17.30	18.06	17.75
1800-1830	1.05	-1.03	-0.99	-1.25	-0.90	-1.21	-1.36	-0.89	-0.09	-0.11	-0.07	-0.07	1.60	1.59	1.69	1.54	245.13	40.59	36.01	54.69	11.44	14.92	15.96	15.79
1830-1900	0.66	-1.20	-1.09	-1.33	-0.93	-1.18	-1.23	-0.79	-0.09	-0.12	-0.06	-0.05	1.36	1.69	1.66	1.56	244.02	45.72	41.91	59.49	10.11	13.50	14.45	14.15
1900-1930	-0.15	-1.14	-0.99	-1.20	-0.89	-1.06	-1.11	-0.70	-0.09	-0.10	-0.05	-0.04	0.97	1.57	1.50	1.40	122.40	47.17	41.76	59.89	9.56	12.66	13.61	13.24
1930-2000	-0.33	-1.16	-1.03	-1.29	-0.98	-1.24	-1.34	-0.81	-0.09	-0.10	-0.06	-0.04	1.06	1.72	1.70	1.53	53.59	43.09	37.53	57.72	8.93	12.09	12.93	12.41
2000-2030	-0.29	-1.17	-1.01	-1.33	-0.92	-1.35	-1.45	-1.00	-0.08	-0.10	-0.07	-0.04	0.98	1.80	1.78	1.68	43.58	41.00	34.97	52.96	8.00	11.50	12.36	11.91
2030-2100	-0.62	-1.32	-1.13	-1.39	-1.04	-1.28	-1.42	-0.92	-0.08	-0.10	-0.07	-0.03	1.24	1.86	1.83	1.69	34.19	46.31	38.72	56.92	8.27	11.12	11.91	11.45
2100-2130	-0.63	-1.44	-1.13	-1.44	-0.99	-1.22	-1.35	-0.94	-0.08	-0.10	-0.06	-0.03	1.22	1.91	1.78	1.74	36.45	49.76	39.86	56.56	7.62	10.66	11.34	10.95
2130-2200	-0.84	-1.69	-1.31	-1.56	-0.88	-1.16	-1.34	-0.83	-0.08	-0.09	-0.06	-0.03	1.26	2.07	1.90	1.79	44.28	55.45	44.36	61.77	7.51	10.70	11.23	10.79
2200-2230	-0.84	-1.84	-1.45	-1.55	-0.76	0.98	-1.20	-0.72	-0.08	-0.10	-0.05	-0.00	1.17	2.11	1.91	1.73	48.11	61.98	50.37	65.13	7.38	10.58	11.28	10.49
2230-2300	-0.50	1.46	-1.19	-1.26	-0.15	-0.46	-0.70	-0.47	0.06	-0.07	-0.02	0.00	0.68	1.60	1.41	1.37	91.11	75.39	61.28	70.62	6.70	9.69	10.39	9.95
2300-2330	0.18	-1.11	-0.67	-0.58	0.22	-0.04	-0.11	0.16	0.06	-0.05	-0.00	0.03	0.38	1.14	0.69	0.64	137.37	87.96	81.12	108.10	6.28	9.23	9.47	8.87
2330-2400	-0.27	-1.33	-0.96	-0.92	-0.36	-0.42	-0.47	-0.33	-0.07	-0.08	-0.03	0.00	0.49	1.40	1.10	1.01	70.89	72.13	65.27	72.16	5.96	9.18	9.68	8.90
0000-0030	-0.42	1.43	-1.04	-1.13	0.48	-0.65	-0.80	-0.55	-0.07	-0.09	-0.04	-0.00	0.67	1.58	1.33	1.28	47.28	65.22	52.49	64.23	5.66	8.24	8.99	8.50
0030-0100	-0.29	-1.44	-1.07	-1.08	-0.28	-0.52	-0.61	-0.28	-0.07	-0.08	-0.04	0.01	0.44	1.54	1.25	1.13	63.04	69.90	59.84	75.85	4.94	7.86	8.18	7.89
0100-0130	-0.29	-1.35	-0.95	-1.06	0.28	-0.51	-0.62	-0.37	-0.07	-0.07	-0.03	0.00	0.43	1.45	1.14	1.13	65.24	69.58	56.88	70.81	5.38	8.15	8.78	8.47
0130-0200	-0.10	-1.10	-0.77	-0.80	-0.43	-0.47	-0.51	-0.28	-0.06	-0.07	-0.03	0.01	0.49	1.24	0.94	0.87	58.56	67.99	57.55	70.90	5.90	8.66	9.06	8.58
0200-0230	-0.02	-1.07	-0.82	-1.07	-0.55	-0.69	-0.72	-0.57	-0.07	-0.08	-0.04	-0.01	0.60	1.28	1.10	1.22	147.58	57.29	48.30	61.78	5.80	8.78	9.55	9.07
0230-0300	0.49	-0.73	0.04	-0.24	-0.11	-0.33	-0.36	-0.32	-0.05	-0.03	-0.01	0.02	0.54	0.84	0.51	0.62	281.40	67.33	208.77	127.73	5.53	8.20	8.44	8.03
0300-0330	0.04	-0.92	-0.74	-1.03	-0.70	-0.80	-0.81	-0.62	-0.07	-0.09	-0.04	0.00	0.75	1.22	1.11	1.21	161.50	48.95	40.48	57.79	5.38	8.51	9.09	8.47
0330-0400	-0.02	-1.04	-0.79	-1.04	0.53	-0.73	-0.82	-0.65	-0.07	-0.08	-0.05	0.01	0.54	1.28	1.15	1.23	171.05	55.32	44.53	58.39	4.55	7.38	8.27	7.88
0400-0430	-0.13	-1.06	-0.78	-1.02	-0.67	-0.75	-0.79	-0.60	-0.08	-0.08	-0.05	0.01	0.69	1.31	1.12	1.19	34.17	54.52	44.52	59.38	4.52	7.45	8.27	7.86
0430-0500	-0.08	-1.07	-0.81	-1.03	-0.83	-0.93	-1.01	-0.73	-0.08	-0.08	-0.06	-0.01	0.84	1.42	1.30	1.27	98.00	49.21	39.00	54.95	3.91	7.09	7.96	7.43
0500-0530	0.44	-0.60	-0.51	-0.80	-0.51	-0.65	-0.85	-0.79	0.07	-0.06	-0.05	-0.01	0.90	0.95	1.04	1.16	208.11	108.85	82.57	43.72	3.60	6.59	7.45	7.01
0530-1600	0.88	-0.00	0.02	-0.10	-0.75	-0.86	-0.90	-1.05	0.08	-0.07	-0.07	-0.02	1.31	0.89	0.94	1.05	306.13	217.24	199.29	22.05	3.40	6.41	6.66	6.09

b. Turbulence statistics.

Tower Time(CDT)	T1 m/s u_*	T2 m/s u_*	T3 m/s u_*	T4 m/s u_*	T1 Km/s $\overline{w'T'}$	T2 Km/s $\overline{w'T'}$	T3 Km/s $\overline{w'T'}$	T4 Km/s $\overline{w'T'}$	T1 $\overline{u'u'}$	T2 $\overline{u'u'}$	T3 $\overline{u'u'}$	T4 $\overline{u'u'}$	T1 $\overline{v'v'}$	T2 $\overline{v'v'}$	T3 $\overline{v'v'}$	T4 $\overline{v'v'}$	T1 $\overline{w'w'}$	T2 $\overline{w'w'}$	T3 $\overline{w'w'}$	T4 $\overline{w'w'}$	T1 C² $\overline{T'T'}$	T2 C² $\overline{T'T'}$	T3 C² $\overline{T'T'}$	T4 C² $\overline{T'T'}$
1730-1800	0.119	0.133	0.138	0.162	-0.028	-0.025	-0.023	-0.014	0.062	0.075	0.109	0.11	0.060	0.051	0.053	0.080	0.017	0.024	0.028	0.045	0.947	0.831	0.815	0.739
1800-1830	0.244	0.088	0.093	0.104	-0.021	-0.017	-0.017	-0.020	0.574	0.041	0.044	0.059	0.534	0.022	0.031	0.031	0.008	0.009	0.012	0.013	0.172	0.189	0.14	0.182
1830-1900	0.178	0.085	0.080	0.083	0.005	-0.009	-0.011	-0.013	0.174	0.037	0.03	0.041	0.579	0.052	0.046	0.046	0.006	0.010	0.009	0.011	0.331	0.329	0.366	0.290
1900-1930	0.099	0.087	0.072	0.076	-0.011	-0.014	-0.009	-0.012	0.041	0.04	0.03	0.039	0.128	0.026	0.027	0.029	0.013	0.011	0.008	0.009	0.102	0.107	0.156	0.138
1930-2000	0.109	0.124	0.104	0.095	-0.015	-0.014	-0.016	-0.012	0.05	0.071	0.055	0.059	0.060	0.041	0.032	0.032	0.019	0.021	0.017	0.014	0.153	0.111	0.201	0.174
2000-2030	0.111	0.135	0.125	0.116	-0.012	-0.016	-0.019	-0.018	0.058	0.081	0.077	0.065	0.035	0.049	0.047	0.049	0.016	0.026	0.024	0.021	0.108	0.087	0.08	0.116
2030-2100	0.152	0.158	0.149	0.138	-0.020	-0.022	-0.023	-0.020	0.11	0.103	0.101	0.133	0.073	0.085	0.064	0.073	0.035	0.033	0.030	0.025	0.059	0.061	0.074	0.098
2100-2130	0.156	0.167	0.145	0.136	-0.017	-0.020	-0.019	-0.020	0.118	0.146	0.117	0.112	0.107	0.096	0.068	0.076	0.033	0.035	0.028	0.026	0.077	0.069	0.064	0.063
2130-2200	0.183	0.187	0.169	0.156	-0.018	-0.021	-0.023	-0.022	0.156	0.16	0.165	0.13	0.093	0.096	0.081	0.075	0.046	0.048	0.040	0.032	0.062	0.052	0.064	0.061
2200-2230	0.168	0.185	0.171	0.165	-0.022	-0.022	-0.026	-0.024	0.115	0.15	0.133	0.148	0.078	0.105	0.100	0.077	0.041	0.053	0.047	0.035	0.077	0.087	0.103	0.102
2230-2300	0.172	0.178	0.141	0.126	-0.025	-0.028	-0.022	-0.017	0.126	0.155	0.132	0.11	0.173	0.201	0.083	0.066	0.023	0.025	0.023	0.021	0.145	0.201	0.245	0.078
2300-2330	0.096	0.058	0.025	0.036	-0.001	-0.004	-0.002	-0.002	0.046	0.042	0.025	0.04	0.033	0.053	0.024	0.065	0.003	0.002	0.001	0.003	0.078	0.145	0.207	0.182
2330-2400	0.091	0.062	0.063	0.052	-0.008	-0.002	0.002	0.000	0.041	0.04	0.053	0.048	0.027	0.022	0.062	0.048	0.003	0.002	0.001	0.000	0.101	0.324	0.177	0.046
0000-0030	0.081	0.072	0.060	0.054	-0.012	-0.011	-0.008	-0.006	0.031	0.032	0.024	0.023	0.044	0.045	0.045	0.042	0.009	0.007	0.006	0.005	0.091	0.160	0.102	0.048
0030-0100	0.089	0.083	0.079	0.067	-0.011	-0.012	-0.008	-0.005	0.033	0.042	0.044	0.048	0.025	0.039	0.041	0.040	0.009	0.010	0.008	0.007	0.102	0.070	0.077	0.092
0100-0130	0.099	0.079	0.053	0.042	-0.008	-0.009	-0.006	-0.003	0.047	0.04	0.027	0.041	0.023	0.030	0.021	0.014	0.006	0.006	0.004	0.002	0.062	0.071	0.069	0.053
0130-0200	0.135	0.096	0.070	0.047	-0.003	-0.008	-0.007	-0.003	0.113	0.039	0.056	0.056	0.010	0.087	0.040	0.036	0.003	0.002	0.002	0.002	0.028	0.108	0.121	0.089
0200-0230	0.088	0.084	0.061	0.038	-0.004	-0.010	-0.006	-0.002	0.037	0.057	0.066	0.034	0.055	0.016	0.015	0.011	0.002	0.003	0.002	0.001	0.171	0.188	0.125	0.047
0230-0300	0.050	0.059	0.072	0.092	0.002	-0.002	-0.006	0.009	0.021	0.054	0.059	0.351	0.034	0.056	0.152	0.043	0.001	0.002	0.001	0.001	0.058	0.164	0.339	0.577
0300-0330	0.076	0.119	0.098	0.059	-0.002	0.016	0.003	0.001	0.087	0.103	0.131	0.117	0.034	0.017	0.020	0.018	0.001	0.003	0.002	0.001	0.488	0.419	0.2	0.181
0330-0400	0.078	0.080	0.084	0.052	0.005	-0.011	0.010	-0.004	0.037	0.044	0.055	0.043	0.013	0.031	0.022	0.026	0.002	0.005	0.004	0.002	0.092	0.121	0.104	0.049
0400-0430	0.054	0.064	0.058	0.032	0.002	-0.007	-0.005	-0.002	0.023	0.033	0.04	0.019	0.011	0.031	0.027	0.022	0.001	0.004	0.003	0.001	0.060	0.077	0.053	0.040
0430-0500	0.050	0.091	0.082	0.070	-0.006	-0.008	-0.006	-0.007	0.014	0.047	0.04	0.044	0.012	0.025	0.025	0.024	0.003	0.011	0.010	0.007	0.140	0.046	0.074	0.079
0500-0530	0.141	0.183	0.126	0.073	-0.008	-0.015	-0.012	-0.007	0.071	0.281	0.152	0.063	0.353	0.068	0.069	0.071	0.008	0.013	0.010	0.008	0.041	0.047	0.064	0.168
0530-0600	0.110	0.161	0.037	0.075	-0.006	-0.012	-0.001	-0.001	0.056	0.207	0.124	0.078	0.345	0.049	0.068	0.004	0.002	0.005	0.001	0.001	0.097	0.116	0.027	0.066

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Table 13. Mean values and turbulence statistics from sonic anemometers at 2 m AGL on towers T2–T4 for IOP7 (17–18 October 1999).

a. Mean values.

Tower Time(CDT)	T2 m/s u_t	T3 m/s u_t	T4 m/s u_t	T2 m/s v_t	T3 m/s v_t	T4 m/s v_t	T2 m/s w_t	T3 m/s w_t	T4 m/s w_t	T2 m/s s_t	T3 m/s s_t	T4 m/s s_t	T2 deg d_t	T3 deg d_t	T4 deg d_t	T2 C T_t	T3 C T_t	T4 C T_t
1830-1900	-0.78	-0.55	-0.93	-1.71	-1.54	-1.08	-0.10	-0.04	-0.03	1.89	1.64	1.43	24.51	19.68	40.67	9.65	8.93	8.98
1900-1930	-0.88	-0.88	-1.00	-1.75	-1.67	-1.23	-0.12	-0.05	-0.04	1.98	1.91	1.61	26.71	30.96	38.38	8.38	8.53	7.94
1930-2000	-0.86	-0.64	-1.09	-1.71	-1.70	-1.29	-0.11	-0.05	-0.04	1.95	1.85	1.75	31.66	42.04	38.61	7.62	7.54	7.60
2000-2030	-1.13	-0.96	-1.24	-1.85	-1.74	-1.28	-0.12	-0.06	-0.04	2.19	2.00	1.80	31.72	29.04	43.92	6.83	7.21	6.71
2030-2100	-1.22	-1.02	-1.20	-1.53	-1.44	-1.11	-0.12	-0.05	-0.03	1.97	1.77	1.64	38.72	35.60	47.41	6.07	6.48	6.48
2100-2130	-1.42	-1.32	-1.27	-1.20	-1.17	-0.78	-0.11	-0.04	-0.03	1.86	1.77	1.51	49.71	48.66	58.19	5.36	5.73	5.73
2130-2200	-1.40	-1.32	-1.52	-1.05	-0.83	-0.63	-0.09	-0.02	-0.02	1.77	1.58	1.65	53.00	58.90	67.71	4.30	4.93	5.10
2200-2230	-1.19	-1.17	-1.33	-0.32	-0.89	-0.39	-0.07	-0.02	-0.01	1.28	1.49	1.40	75.76	53.85	74.21	4.10	4.81	4.16
2230-2300	-1.22	-1.03	-1.15	-0.43	-0.25	-0.31	-0.07	-0.00	-0.01	1.33	1.09	1.26	71.99	77.39	78.15	3.91	4.33	4.13
2300-2330	-1.02	-0.99	-1.18	-0.14	-0.17	0.11	-0.04	-0.00	0.01	1.03	1.01	1.19	82.32	80.39	95.06	3.41	3.94	3.86
2330-2400	-1.07	-0.99	-0.94	0.09	0.32	0.30	-0.03	0.01	0.02	1.09	1.05	1.00	94.65	107.07	108.41	3.20	3.65	3.65
0000-0030	-1.11	-1.01	-0.84	0.49	0.28	0.69	-0.01	0.01	0.04	1.22	1.05	1.09	113.86	105.90	129.37	2.71	3.19	2.97
0030-0100	-1.27	-1.24	-1.23	0.46	-0.63	0.20	-0.02	-0.02	0.01	1.36	1.42	1.31	109.97	63.47	99.96	2.18	2.47	2.32
0100-0130	-1.41	-1.12	-1.49	0.41	-0.21	-0.26	-0.03	-0.01	-0.01	1.47	1.16	1.55	106.82	80.63	81.09	2.20	2.86	2.52
0130-0200	-1.23	-0.93	-0.91	0.33	0.20	0.20	-0.04	0.00	0.02	1.28	0.96	0.95	105.04	102.13	104.09	2.79	3.66	2.90
0200-0230	-1.12	-1.05	-0.90	0.27	0.26	0.50	-0.02	0.01	0.03	1.17	1.10	1.05	103.89	103.60	119.17	3.50	4.53	3.91
0230-0300	-1.31	-1.08	-1.06	0.26	0.08	0.54	-0.02	0.00	0.03	1.35	1.10	1.21	100.85	93.88	117.02	4.13	4.92	4.41
0300-0330	-1.27	-1.01	-0.98	0.14	0.14	0.38	-0.03	-0.00	0.02	1.29	1.04	1.07	96.51	98.00	111.10	4.50	5.33	4.73
0330-0400	-1.35	-1.02	-0.94	0.14	0.03	0.38	-0.04	-0.01	0.02	1.37	1.03	1.02	96.07	91.36	112.25	4.77	5.14	4.89
0400-0430	-1.35	-1.20	-1.03	0.08	0.16	0.31	-0.04	-0.00	0.02	1.35	1.22	1.09	93.38	97.23	106.74	4.72	5.21	4.52
0430-0500	-1.39	-1.29	-1.24	0.23	0.03	0.49	-0.03	-0.00	0.02	1.41	1.29	1.34	99.54	91.40	112.14	4.53	4.81	4.20
0500-0530	-1.39	-1.42	-1.28	0.05	0.11	0.35	-0.04	-0.00	0.02	1.40	1.43	1.33	92.42	94.52	105.39	3.83	3.57	3.53
0530-1600	-1.75	-1.49	-1.50	0.45	0.41	0.60	-0.03	0.01	0.03	1.82	1.57	1.63	104.40	106.47	111.75	2.34	2.73	2.37
1600-1630	-1.22	-0.11	-0.45	0.41	0.17	0.54	-0.01	-0.00	0.06	1.31	0.64	0.86	108.34	207.49	152.39	1.70	2.12	1.78

b. Turbulence statistics.

Tower Time(CDT)	T2 m/s ustar$_t$	T3 m/s ustar$_t$	T4 m/s ustar$_t$	T2 Km/s H_t	T3 Km/s H_t	T4 Km/s H_t	T2 m^2/s^2 u'u'$_t$	T3 m^2/s^2 u'u'$_t$	T4 m^2/s^2 u'u'$_t$	T2 m^2/s^2 v'v'$_t$	T3 m^2/s^2 v'v'$_t$	T4 m^2/s^2 v'v'$_t$	T2 m^2/s^2 w'w'$_t$	T3 m^2/s^2 w'w'$_t$	T4 m^2/s^2 w'w'$_t$	T2 C^2 T'T'$_t$	T3 C^2 T'T'$_t$	T4 C^2 T'T'$_t$
1830-1900	0.122	0.056	0.047	0.013	0.001	0.004	0.076	0.049	0.032	0.025	0.015	0.019	0.010	0.002	0.001	0.605	0.910	1.051
1900-1930	0.120	0.093	0.072	-0.021	-0.014	-0.011	0.070	0.107	0.066	0.079	0.069	0.073	0.019	0.013	0.004	0.268	0.262	0.336
1930-2000	0.144	0.122	0.111	-0.032	-0.018	-0.020	0.117	0.115	0.108	0.126	0.119	0.236	0.025	0.022	0.017	0.647	0.523	1.487
2000-2030	0.162	0.128	0.120	-0.029	-0.023	-0.022	0.105	0.084	0.069	0.075	0.055	0.051	0.039	0.027	0.024	0.244	0.120	0.136
2030-2100	0.122	0.097	0.106	-0.023	-0.018	-0.018	0.065	0.059	0.061	0.070	0.045	0.040	0.023	0.014	0.018	0.159	0.136	0.108
2100-2130	0.056	0.052	0.059	-0.004	-0.009	-0.009	0.023	0.024	0.029	0.022	0.019	0.057	0.003	0.005	0.006	0.114	0.131	0.225
2130-2200	0.092	0.081	0.072	-0.017	-0.015	-0.013	0.050	0.067	0.035	0.038	0.049	0.025	0.008	0.006	0.008	0.270	0.257	0.117
2200-2230	0.090	0.066	0.067	-0.001	-0.003	-0.009	0.019	0.051	0.050	0.108	0.054	0.044	0.001	0.001	0.002	0.071	0.080	0.207
2230-2300	0.095	0.042	0.108	-0.003	-0.001	-0.015	0.026	0.014	0.081	0.102	0.060	0.154	0.001	0.000	0.003	0.048	0.055	0.323
2300-2330	0.047	0.018	0.025	-0.004	-0.000	0.000	0.023	0.015	0.012	0.006	0.012	0.007	0.001	0.000	0.000	0.152	0.029	0.031
2330-2400	0.038	0.027	0.037	0.000	-0.000	-0.001	0.017	0.029	0.022	0.043	0.022	0.030	0.000	0.000	0.000	0.029	0.034	0.119
0000-0030	0.017	0.029	0.027	-0.000	0.001	0.000	0.013	0.015	0.013	0.007	0.019	0.012	0.000	0.000	0.000	0.025	0.076	0.057
0030-0100	0.024	0.085	0.089	0.001	-0.009	-0.003	0.019	0.052	0.034	0.018	0.064	0.157	0.000	0.010	0.004	0.095	0.073	0.229
0100-0130	0.058	0.092	0.137	-0.004	-0.006	-0.014	0.059	0.082	0.128	0.007	0.060	0.083	0.004	0.011	0.022	0.088	0.080	0.079
0130-0200	0.072	0.056	0.061	-0.005	-0.002	-0.003	0.028	0.031	0.044	0.010	0.029	0.038	0.007	0.006	0.006	0.110	0.129	0.103
0200-0230	0.077	0.080	0.071	-0.004	-0.003	-0.003	0.035	0.053	0.039	0.037	0.032	0.043	0.009	0.013	0.011	0.041	0.046	0.042
0230-0300	0.095	0.099	0.095	-0.005	-0.006	-0.006	0.056	0.060	0.055	0.042	0.040	0.054	0.015	0.015	0.019	0.020	0.017	0.019
0300-0330	0.087	0.080	0.089	-0.005	-0.005	-0.006	0.037	0.041	0.050	0.027	0.024	0.035	0.011	0.011	0.014	0.029	0.034	0.053
0330-0400	0.082	0.048	0.065	-0.007	-0.004	-0.004	0.038	0.029	0.031	0.023	0.015	0.018	0.011	0.005	0.008	0.037	0.050	0.039
0400-0430	0.023	0.018	0.026	-0.001	-0.001	-0.001	0.009	0.012	0.014	0.007	0.016	0.015	0.001	0.001	0.001	0.018	0.025	0.047
0430-0500	0.030	0.021	0.012	-0.002	-0.000	0.000	0.016	0.016	0.026	0.010	0.012	0.017	0.001	0.000	0.000	0.038	0.049	0.119
0500-0530	0.045	0.034	0.013	0.002	-0.005	-0.002	0.040	0.031	0.024	0.021	0.028	0.014	0.001	0.003	0.001	0.071	0.452	0.157
0530-0600	0.066	0.124	0.103	-0.007	-0.015	-0.018	0.076	0.155	0.128	0.040	0.080	0.057	0.007	0.026	0.022	0.306	0.072	0.126
0600-0630	0.048	0.079	0.146	-0.003	-0.003	0.009	0.051	0.281	0.307	0.067	0.236	0.124	0.008	0.005	0.013	0.215	0.139	0.311

Table 14. Mean values and turbulence statistics from sonic anemometers at 2 m AGL on towers T1–T3 for IOP8 (19–20 October 1999).

a. Mean values.

Tower Time(CDT)	T1 u_t m/s	T2 u_t m/s	T3 u_t m/s	T1 v_t m/s	T2 v_t m/s	T3 v_t m/s	T1 w_t m/s	T2 w_t m/s	T3 w_t m/s	T1 s_r m/s	T2 s_r m/s	T3 s_r m/s	T1 d_t deg	T2 d_t deg	T3 d_t deg	T1 T_t C	T2 T_t C	T3 T_t C
1800-1830	0.88	0.16	0.12	-1.60	-1.70	-1.47	-0.11	-0.11	-0.04	1.84	1.71	1.48	331.41	319.90	255.03	8.60	11.59	11.64
1830-1900	0.50	-0.21	-0.16	-1.62	-1.71	-1.49	-0.11	-0.12	-0.04	1.71	1.73	1.50	340.68	59.09	54.60	8.15	11.37	11.66
1900-1930	-0.16	-0.90	-0.74	-1.58	-1.65	-1.42	-0.11	-0.12	-0.02	1.59	1.88	1.60	29.21	28.54	27.55	8.17	11.40	11.49
1930-2000	0.03	-0.73	-0.49	-1.26	-1.64	-1.34	-0.09	-0.11	-0.03	1.35	1.81	1.44	182.28	24.33	20.36	6.80	10.33	10.03
2000-2030	-0.31	-1.61	-1.06	0.77	0.40	0.08	-0.04	-0.03	0.03	0.87	1.80	1.26	153.74	101.21	93.07	4.12	7.70	7.98
2030-2100	-0.46	-1.81	-1.79	0.26	0.29	0.21	-0.06	-0.04	0.01	0.57	1.84	1.81	117.49	99.07	96.95	3.52	6.87	7.51
2100-2130	-0.30	-1.75	-1.77	0.27	0.17	0.22	-0.06	-0.05	0.01	0.42	1.76	1.78	133.73	95.37	96.92	2.94	6.44	7.27
2130-2200	-0.52	-1.84	-1.73	-0.17	-0.07	-0.08	-0.08	-0.06	-0.00	0.57	1.86	1.75	71.52	87.87	87.14	2.51	5.75	6.44
2200-2230	-0.49	-1.84	-1.74	0.16	0.15	0.12	-0.07	-0.06	0.00	0.57	1.86	1.76	109.44	94.67	93.94	2.29	5.34	6.09
2230-2300	-0.47	-1.91	-1.76	0.05	0.08	0.18	-0.07	-0.06	0.01	0.56	1.92	1.78	97.83	92.62	95.82	1.77	4.82	5.56
2300-2330	-0.18	-1.60	-1.62	0.55	0.45	0.36	-0.05	-0.02	0.01	0.62	1.68	1.68	154.83	105.46	103.00	1.71	4.83	5.41
2330-2400	-0.26	-1.79	-1.79	0.13	0.04	0.11	-0.07	-0.05	0.00	0.35	1.80	1.80	111.14	91.33	93.70	1.16	4.28	5.00
0000-0030	-0.28	-1.60	-1.65	0.57	0.55	0.50	-0.05	-0.02	0.02	0.64	1.70	1.73	152.40	108.89	106.79	1.13	4.07	4.60
0030-0100	-0.31	-1.75	-1.58	0.52	0.53	0.50	-0.05	-0.02	0.02	0.62	1.83	1.66	147.48	106.80	107.57	1.15	4.24	4.80
0100-0130	-0.34	-1.83	-1.74	0.69	0.65	0.63	-0.05	-0.01	0.02	0.79	1.96	1.86	151.18	109.52	109.75	1.67	4.78	5.38
0130-0200	-0.02	-1.39	-1.23	0.91	0.74	0.63	-0.04	-0.00	0.03	0.92	1.59	1.39	178.90	117.89	116.78	1.75	4.73	5.26
0200-0230	0.09	-1.35	-1.35	1.37	1.11	0.91	-0.03	0.02	0.03	1.38	1.76	1.64	183.82	129.38	124.07	2.21	4.96	5.35
0230-0300	0.14	-1.18	-1.14	1.61	1.43	0.99	-0.03	0.03	0.04	1.62	1.87	1.52	185.27	140.39	131.06	2.55	5.41	5.41
0300-0330	0.23	-1.07	-0.88	1.61	1.60	1.28	-0.02	0.04	0.04	1.65	1.95	1.59	188.57	145.75	144.50	2.91	5.90	6.16
0330-0400	0.43	-0.89	-0.67	1.52	1.61	1.28	-0.03	0.05	0.04	1.59	1.85	1.46	196.10	150.94	152.26	2.93	6.13	6.51
0400-0430	0.31	-1.02	-0.85	1.68	1.72	1.48	-0.02	0.05	0.05	1.72	2.01	1.73	190.65	149.19	150.48	3.28	6.27	6.64
0430-0500	0.52	-0.85	-0.62	1.65	1.84	1.51	-0.02	0.06	0.05	1.74	2.04	1.64	197.86	154.95	157.96	2.95	6.12	6.52
0500-0530	0.60	-0.84	-0.81	1.57	1.90	1.87	-0.02	0.06	0.05	1.70	2.09	2.06	201.19	156.05	156.43	2.52	5.75	6.34
0530-0600	0.93	-0.50	-0.54	1.60	1.88	1.85	-0.02	0.07	0.05	1.87	1.96	1.94	210.29	164.83	163.50	2.59	5.54	6.07
0600-0630	1.11	-0.23	-0.26	1.45	1.77	1.73	-0.01	0.06	0.04	1.85	1.83	1.78	217.20	172.47	171.83	2.44	5.43	5.91
0630-0700	1.42	0.10	0.04	1.88	2.25	2.18	-0.01	0.08	0.05	2.38	2.27	2.20	217.34	182.37	181.06	2.71	5.75	6.29
0700-0730	1.32	0.12	0.08	2.04	2.38	2.31	-0.01	0.10	0.05	2.47	2.42	2.34	213.21	182.84	181.89	3.32	6.29	6.84
0730-0800	1.30	0.18	0.12	2.57	3.27	3.31	0.03	0.11	0.07	2.94	3.34	3.38	206.78	183.08	181.90	5.48	8.44	9.08
0800-0830	1.51	0.33	0.33	3.54	3.88	3.73	0.03	0.17	0.13	3.92	3.96	3.81	203.36	184.87	185.03	7.84	10.84	11.45
0830-0900	1.85	0.69	0.67	4.61	4.99	4.71	0.02	0.23	0.13	5.05	5.12	4.85	201.95	187.59	188.00	9.85	12.92	13.57
0900-0930	2.58	1.49	1.40	4.27	4.90	4.86	0.02	0.19	0.09	5.12	5.23	5.18	211.68	197.21	195.71	11.78	14.78	15.49
0930-1000	3.26	2.39	2.29	3.80	4.42	4.99	-0.02	0.17	0.08	5.13	5.13	5.58	220.63	208.52	204.74	13.34	16.30	16.93

b. Turbulence statistics.

Tower Time(CDT)	T1 $ustar_t$ m/s	T2 $ustar_t$ m/s	T3 $ustar_t$ m/s	T1 H_t Km/s	T2 H_t Km/s	T3 H_t Km/s	T1 $u'u'_t$ m²/s²	T2 $u'u'_t$ m²/s²	T3 $u'u'_t$ m²/s²	T1 $v'v'_t$ m²/s²	T2 $v'v'_t$ m²/s²	T3 $v'v'_t$ m²/s²	T1 $w'w'_t$ m²/s²	T2 $w'w'_t$ m²/s²	T3 $w'w'_t$ m²/s²	T1 $T'T'_t$ C²	T2 $T'T'_t$ C²	T3 $T'T'_t$ C²
1800-1830	0.029	0.023	0.016	-0.002	-0.001	-0.000	0.017	0.015	0.011	0.036	0.025	0.032	0.003	0.002	0.001	0.304	0.332	0.445
1830-1900	0.010	0.033	0.028	-0.006	-0.003	-0.001	0.017	0.012	0.014	0.046	0.044	0.017	0.003	0.001	0.000	0.116	0.120	0.223
1900-1930	0.043	0.058	0.029	-0.006	-0.010	-0.003	0.014	0.019	0.023	0.008	0.013	0.007	0.003	0.004	0.001	0.172	0.186	0.298
1930-2000	0.105	0.079	0.042	0.012	-0.016	-0.002	0.411	0.034	0.037	0.027	0.054	0.024	0.005	0.006	0.001	1.439	0.416	0.534
2000-2030	0.041	0.091	0.107	-0.002	-0.009	-0.023	0.077	0.170	0.135	0.048	0.359	0.412	0.002	0.002	0.003	0.136	1.074	1.884
2030-2100	0.032	0.025	0.021	0.000	0.001	0.000	0.009	0.002	0.020	0.043	0.020	0.008	0.000	0.000	0.000	0.116	0.171	0.075
2100-2130	0.043	0.016	0.012	0.001	0.000	-0.000	0.009	0.008	0.004	0.009	0.005	0.005	0.001	0.001	0.000	0.044	0.073	0.083
2130-2200	0.060	0.053	0.049	-0.005	-0.002	-0.005	0.018	0.024	0.032	0.029	0.044	0.052	0.005	0.003	0.004	0.052	0.071	0.093
2200-2230	0.092	0.056	0.066	-0.011	-0.006	-0.009	0.040	0.023	0.052	0.047	0.041	0.067	0.008	0.005	0.007	0.097	0.194	0.095
2230-2300	0.061	0.068	0.076	-0.004	-0.005	-0.010	0.017	0.023	0.043	0.093	0.041	0.032	0.004	0.005	0.010	0.043	0.065	0.076
2300-2330	0.064	0.058	0.045	0.001	-0.002	-0.003	0.054	0.018	0.015	0.050	0.066	0.060	0.002	0.001	0.002	0.064	0.026	0.058
2330-2400	0.038	0.053	0.029	-0.001	-0.001	-0.001	0.007	0.016	0.009	0.046	0.035	0.026	0.001	0.002	0.001	0.034	0.064	0.064
0000-0030	0.037	0.031	0.010	-0.001	-0.000	-0.001	0.016	0.005	0.006	0.011	0.021	0.018	0.001	0.000	0.001	0.017	0.023	0.083
0030-0100	0.048	0.025	0.017	-0.003	-0.000	-0.000	0.024	0.006	0.007	0.014	0.015	0.013	0.001	0.000	0.000	0.043	0.033	0.055
0100-0130	0.053	0.044	0.026	-0.004	0.001	0.000	0.051	0.004	0.005	0.024	0.050	0.031	0.002	0.001	0.001	0.107	0.070	0.074
0130-0200	0.049	0.046	0.031	-0.008	-0.002	-0.002	0.067	0.023	0.025	0.009	0.053	0.033	0.002	0.002	0.001	0.106	0.097	0.100
0200-0230	0.030	0.033	0.023	-0.005	-0.002	-0.003	0.037	0.016	0.031	0.017	0.045	0.021	0.004	0.002	0.002	0.088	0.093	0.061
0230-0300	0.088	0.053	0.046	-0.013	-0.007	-0.007	0.078	0.057	0.025	0.040	0.036	0.029	0.014	0.008	0.006	0.107	0.136	0.151
0300-0330	0.098	0.079	0.063	-0.015	-0.011	-0.009	0.082	0.072	0.078	0.068	0.091	0.116	0.017	0.015	0.014	0.121	0.157	0.225
0330-0400	0.063	0.082	0.073	-0.010	-0.011	-0.012	0.043	0.073	0.055	0.052	0.055	0.050	0.010	0.014	0.015	0.128	0.118	0.116
0400-0430	0.077	0.078	0.082	-0.012	-0.012	-0.014	0.051	0.064	0.080	0.041	0.059	0.068	0.012	0.015	0.017	0.114	0.117	0.102
0430-0500	0.087	0.088	0.076	-0.016	-0.014	-0.014	0.052	0.076	0.210	0.047	0.054	0.050	0.015	0.017	0.021	0.123	0.102	0.133
0500-0530	0.071	0.095	0.113	-0.011	-0.014	-0.019	0.046	0.077	0.089	0.073	0.052	0.055	0.012	0.018	0.025	0.167	0.172	0.147
0530-0600	0.099	0.084	0.110	-0.017	-0.012	-0.017	0.082	0.081	0.087	0.064	0.057	0.054	0.026	0.021	0.026	0.100	0.097	0.086
0600-0630	0.091	0.073	0.096	-0.014	-0.010	-0.016	0.130	0.109	0.091	0.108	0.142	0.125	0.022	0.021	0.021	0.151	0.148	0.091
0630-0700	0.135	0.176	0.157	-0.015	-0.024	-0.022	0.155	0.207	0.181	0.104	0.092	0.095	0.040	0.044	0.051	0.066	0.097	0.074
0700-0730	0.174	0.194	0.188	-0.009	-0.010	-0.014	0.222	0.268	0.257	0.214	0.142	0.123	0.054	0.059	0.061	0.252	0.312	0.312
0730-0800	0.235	0.246	0.282	0.016	0.002	0.019	0.552	0.609	0.569	0.379	0.404	0.390	0.097	0.093	0.117	0.425	0.300	0.325
0800-0830	0.324	0.321	0.349	0.034	0.033	0.036	1.075	0.911	0.817	0.585	0.509	0.498	0.160	0.156	0.168	0.747	0.767	0.733
0830-0900	0.414	0.458	0.446	0.058	0.067	0.060	1.548	1.552	1.394	0.882	0.815	0.890	0.227	0.244	0.259	0.294	0.373	0.354
0900-9300	0.433	0.453	0.480	0.071	0.087	0.087	1.422	1.514	1.471	1.348	1.055	1.273	0.248	0.248	0.261	0.567	0.523	0.536
9300-1000	0.433	0.460	0.480	0.099	0.113	0.105	1.308	1.545	1.440	1.276	1.074	1.273	0.262	0.272	0.261	0.488	0.545	0.536

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Table 15. Mean values and turbulence statistics from sonic anemometers at 2 m AGL on towers T1–T4 for IOP9 (20–21 October 1999).

a. Mean values.

Tower Time(CDT)	u T1 m/s	u T2 m/s	u T3 m/s	u T4 m/s	v T1 m/s	v T2 m/s	v T3 m/s	v T4 m/s	w T1 m/s	w T2 m/s	w T3 m/s	w T4 m/s	s T1 m/s	s T2 m/s	s T3 m/s	s T4 m/s	d T1 deg	d T2 deg	d T3 deg	d T4 deg	T T1 C	T T2 C	T T3 C	T T4 C
1700-1730	2.61	1.85	1.96	2.06	2.20	2.38	2.54	1.88	-0.03	0.07	0.04	0.16	3.47	3.07	3.26	2.84	229.96	217.64	217.40	227.49	17.93	21.03	21.50	21.18
1730-1800	1.31	0.61	0.60	0.66	1.60	1.79	1.18	1.01	-0.05	0.05	0.03	0.07	2.09	1.92	1.34	1.23	219.31	198.07	206.74	212.57	16.11	19.07	18.73	18.59
1800-1830	0.82	0.10	0.31	0.33	1.54	1.23	0.50	0.45	-0.05	0.03	0.01	0.04	1.75	1.27	0.62	0.57	208.02	196.96	219.99	217.60	15.22	17.79	17.77	17.25
1830-1900	1.04	0.15	0.20	0.21	1.13	0.59	0.58	0.31	-0.05	-0.01	0.02	0.04	1.58	0.97	0.87	0.51	223.97	223.47	216.07	223.99	13.34	16.37	16.88	15.95
1900-1930	0.17	-0.98	-0.90	-0.32	1.51	1.53	0.67	0.33	-0.03	0.03	0.06	0.01	1.55	1.83	1.14	0.51	186.42	147.08	125.87	133.23	12.22	15.74	15.56	14.18
1930-2000	0.11	-1.53	-1.46	0.89	1.42	1.16	0.61	0.26	-0.03	0.00	0.06	0.02	1.53	1.95	1.60	0.95	183.04	127.14	112.90	103.92	10.96	13.89	13.94	12.37
2000-2030	-0.14	-1.64	-1.61	-1.04	1.39	1.32	1.07	0.90	-0.04	0.01	0.06	0.05	1.55	2.16	2.00	1.45	174.65	130.16	124.50	130.54	10.30	13.34	13.49	12.30
2030-2100	1.08	-0.43	-0.29	0.13	1.42	1.57	1.06	0.69	-0.03	0.04	0.05	0.05	1.84	1.65	1.13	0.72	215.87	164.52	168.91	191.25	10.54	13.63	13.62	12.93
2100-2130	0.04	-1.07	-0.82	-0.50	1.43	1.36	0.73	0.21	-0.03	0.03	0.05	0.04	1.48	1.76	1.19	0.62	181.07	141.09	125.17	116.21	9.65	12.84	12.67	11.93
2130-2200	0.44	-0.52	-0.28	-0.09	1.35	1.28	0.39	0.56	-0.03	0.04	0.04	0.05	1.44	1.39	0.65	0.60	198.71	158.00	153.31	170.77	8.89	12.03	12.30	12.46
2200-2230	0.92	-0.03	0.01	0.29	1.90	1.99	1.56	0.87	-0.02	0.07	0.05	0.07	2.14	2.02	1.59	0.94	205.81	178.08	179.41	193.94	9.88	12.98	13.30	12.31
2230-2300	1.25	0.30	0.38	0.60	2.38	2.21	1.79	1.26	-0.01	0.08	0.05	0.09	2.72	2.26	1.85	1.42	208.08	187.83	192.73	205.40	10.35	13.30	13.66	13.09
2300-2330	1.16	0.23	0.27	0.43	1.96	1.80	1.37	1.38	-0.01	0.07	0.03	0.10	2.31	1.85	1.42	1.46	210.88	187.41	191.11	196.93	9.99	12.96	13.23	12.69
2330-2400	0.93	-0.04	0.02	0.26	2.07	2.02	1.55	1.41	-0.01	0.06	0.06	0.10	2.31	2.05	1.58	1.45	204.54	178.84	181.21	190.52	9.65	12.73	13.06	12.28
0000-0030	0.65	-0.31	-0.24	0.14	1.94	2.02	1.67	1.27	-0.02	0.07	0.07	0.10	2.07	2.07	1.71	1.30	198.94	170.97	171.44	186.01	9.09	12.33	12.85	12.00
0030-0100	1.07	0.11	0.15	0.48	2.41	2.44	2.13	1.72	-0.02	0.09	0.06	0.13	2.68	2.49	2.18	1.81	203.83	182.07	183.36	195.11	9.44	12.53	12.98	12.19
0100-0130	1.62	0.66	0.67	0.98	2.80	2.81	2.61	2.04	-0.01	0.11	0.06	0.13	3.24	2.92	2.73	2.29	210.31	193.23	194.28	206.01	9.49	12.45	13.06	12.55
0130-0200	1.56	0.52	0.54	0.68	1.86	1.77	1.68	1.50	-0.01	0.05	0.04	0.13	2.45	1.87	1.80	1.68	220.31	196.63	198.02	204.58	8.61	11.43	11.92	11.57
0200-0230	1.15	0.21	0.26		1.44	1.24	1.38		-0.01	0.04	0.04		1.88	1.29	1.42		219.67	192.83	191.77		7.69	10.67	11.20	
0230-0300	1.22	0.28	0.24		1.73	1.67	1.70		-0.01	0.05	0.04		2.15	1.73	1.74		215.83	190.57	187.82		7.33	10.13	10.50	
0300-0330	1.29	0.19	0.18		1.39	1.62	1.38		-0.02	0.04	0.03		2.10	1.77	1.48		227.28	200.56	194.53		6.58	9.90	10.34	
0330-0400	1.68	0.59	0.50		1.07	1.26	1.06		-0.03	0.03	0.01		2.01	1.42	1.18		237.63	204.88	205.38		6.71	9.80	9.60	
0400-0430	1.46	0.37	0.31		1.12	1.41	1.28		-0.03	0.04	0.03		1.85	1.49	1.34		232.24	195.11	194.84		6.12	9.10	9.20	
0430-0500	1.58	0.47	0.39		1.26	1.32	1.19		-0.03	0.03	0.02		2.04	1.42	1.26		231.68	200.56	198.59		6.11	8.97	9.20	
0500-0530	2.23	0.87	0.62		0.81	0.72	0.55		-0.04	0.00	0.00		2.39	1.17	0.86		250.16	232.91	229.39		5.15	8.70	8.66	
0530-0600	1.76	0.59	0.48		0.74	0.62	0.64		-0.03	-0.00	0.01		1.94	0.89	0.85		247.54	225.02	220.72		5.15	8.53	8.71	
0600-0630	0.78	-0.28	-0.31		0.88	1.11	0.99		-0.03	0.03	0.04		1.20	1.24	1.18		218.24	165.09	162.55		4.98	8.23	8.38	
0630-0700	0.43	-0.64	-0.85		0.52	0.88	0.74		-0.04	0.01	0.04		0.68	1.10	1.16		220.68	143.87	130.26		4.65	8.09	8.31	
0700-0730	0.22	-0.80	-0.77		0.87	0.48	0.63		-0.03	-0.01	0.03		0.91	1.00	1.03		194.10	119.63	126.87		4.61	7.51	8.19	
0730-0800	0.34	-0.47	-0.46		0.89	0.93	0.90		-0.02	0.01	0.05		0.99	1.09	1.04		201.34	152.35	151.65		6.83	9.96	10.55	

b. Turbulence statistics.

Tower Time(CDT)	ustar T1 m/s	ustar T2 m/s	ustar T3 m/s	ustar T4 m/s	H T1 Km/s	H T2 Km/s	H T3 Km/s	H T4 Km/s	u'u' T1 m^2/s^2	u'u' T2	u'u' T3	u'u' T4	v'v' T1	v'v' T2	v'v' T3	v'v' T4	w'w' T1	w'w' T2	w'w' T3	w'w' T4	TT T1 C^2	TT T2	TT T3	TT T4
1700-1730	0.263	0.259	0.362	0.370	-0.013	0.015	-0.045	-0.049	0.923	0.864	1.254	1.050	0.378	0.317	0.353	0.308	0.125	0.117	0.126	0.132	0.388	0.353	0.580	0.531
1730-1800	0.111	0.153	0.086	0.127	-0.016	0.030	-0.012	-0.021	0.145	0.170	0.106	0.122	0.081	0.117	0.041	0.052	0.030	0.033	0.012	0.024	0.200	0.373	0.302	0.455
1800-1830	0.051	0.092	0.021	0.055	-0.011	-0.004	-0.003	-0.003	0.041	0.490	0.076	0.044	0.028	0.030	0.036	0.020	0.007	0.011	0.004	0.005	0.486	0.731	0.122	0.239
1830-1900	0.063	0.186	0.141	0.073	-0.000	0.016	-0.002	-0.003	0.151	0.489	0.165	0.093	0.145	0.315	0.399	0.122	0.005	0.006	0.003	0.002	0.946	0.467	0.494	0.409
1900-1930	0.026	0.051	0.053	0.056	-0.002	-0.003	-0.007	0.003	0.042	0.063	0.095	0.027	0.109	0.037	0.043	0.050	0.002	0.003	0.003	0.003	0.243	0.208	0.352	0.349
1930-2000	0.043	0.067	0.042	0.076	0.004	0.002	-0.002	-0.008	0.063	0.030	0.051	0.215	0.297	0.121	0.050	0.039	0.002	0.002	0.002	0.005	0.762	0.429	0.301	0.344
2000-2030	0.077	0.060	0.046	0.075	0.009	0.007	0.006	-0.007	0.067	0.123	0.116	0.204	0.467	0.174	0.212	0.164	0.006	0.005	0.004	0.008	0.285	0.265	0.276	0.161
2030-2100	0.051	0.031	0.103	0.049	-0.012	-0.008	0.003	-0.005	0.125	0.072	0.263	0.058	0.226	0.077	0.050	0.022	0.010	0.008	0.009	0.006	0.230	0.202	0.237	0.307
2100-2130	0.048	0.052	0.076	0.082	-0.009	-0.006	0.008	-0.004	0.068	0.068	0.187	0.077	0.151	0.119	0.154	0.076	0.009	0.011	0.012	0.006	0.331	0.431	0.532	0.243
2130-2200	0.059	0.045	0.136	0.043	-0.012	0.009	-0.001	0.004	0.066	0.108	0.384	0.038	0.063	0.046	0.070	0.049	0.013	0.010	0.011	0.006	0.210	0.143	0.230	0.394
2200-2230	0.132	0.075	0.133	0.112	-0.018	-0.010	-0.028	-0.020	0.306	0.265	0.151	0.199	0.124	0.140	0.108	0.029	0.045	0.038	0.029	0.014	0.397	0.423	0.345	0.450
2230-2300	0.191	0.181	0.171	0.146	-0.028	-0.032	-0.033	-0.027	0.302	0.246	0.283	0.157	0.165	0.131	0.104	0.062	0.068	0.061	0.047	0.034	0.096	0.121	0.233	0.196
2300-2330	0.169	0.154	0.122	0.127	-0.024	-0.030	-0.022	0.025	0.202	0.182	0.103	0.097	0.149	0.095	0.069	0.054	0.054	0.046	0.028	0.024	0.109	0.135	0.162	0.264
2330-2400	0.160	0.124	0.118	0.111	-0.026	-0.023	-0.023	-0.020	0.210	0.214	0.143	0.079	0.192	0.124	0.087	0.045	0.058	0.047	0.034	0.022	0.103	0.110	0.120	0.187
0000-0030	0.126	0.106	0.114	0.117	-0.024	-0.020	-0.021	0.021	0.171	0.226	0.169	0.098	0.117	0.110	0.093	0.043	0.047	0.044	0.039	0.023	0.119	0.129	0.139	0.171
0030-0100	0.177	0.199	0.184	0.177	-0.027	-0.033	-0.033	-0.030	0.458	0.377	0.318	0.209	0.223	0.233	0.164	0.095	0.078	0.077	0.061	0.044	0.164	0.134	0.133	0.163
0100-0130	0.238	0.244	0.238	0.250	-0.029	-0.036	-0.035	-0.043	0.499	0.486	0.397	0.379	0.257	0.209	0.200	0.155	0.096	0.095	0.087	0.091	0.106	0.120	0.116	0.163
0130-0200	0.172	0.141	0.159	0.176	-0.024	-0.024	-0.025	-0.027	0.228	0.215	0.201	0.144	0.146	0.103	0.129	0.094	0.052	0.041	0.037	0.049	0.126	0.162	0.169	0.393
0200-0230	0.102	0.084	0.090		-0.015	-0.011	-0.012		0.183	0.251	0.142		0.140	0.070	0.050		0.028	0.020	0.015		0.249	0.148	0.170	
0230-0300	0.131	0.086	0.102		-0.017	0.018	-0.014		0.142	0.170	0.124		0.153	0.149	0.091		0.033	0.023	0.017		0.189	0.140	0.177	
0300-0330	0.103	0.112	0.098		-0.015	-0.020	-0.015		0.326	1.011	0.484		0.744	0.353	0.228		0.039	0.042	0.029		0.159	0.118	0.085	
0330-0400	0.063	0.111	0.060		-0.009	-0.017	-0.005		0.077	0.120	0.050		0.071	0.063	0.023		0.013	0.022	0.006		0.106	0.141	0.102	
0400-0430	0.073	0.090	0.074		-0.011	-0.015	-0.008		0.097	0.088	0.115		0.064	0.081	0.048		0.013	0.015	0.008		0.162	0.154	0.138	
0430-0500	0.079	0.077	0.065		-0.013	-0.012	-0.007		0.100	0.141	0.080		0.089	0.056	0.038		0.019	0.014	0.008		0.110	0.112	0.111	
0500-0530	0.071	0.090	0.057		-0.011	-0.011	-0.006		0.062	0.142	0.065		0.083	0.099	0.052		0.011	0.018	0.007		0.250	0.171	0.124	
0530-0600	0.054	0.062	0.071		-0.001	-0.006	-0.004		0.075	0.058	0.095		0.111	0.065	0.080		0.006	0.008	0.005		0.197	0.101	0.133	
0600-0630	0.110	0.067	0.083		0.009	0.002	-0.002		0.283	0.041	0.050		0.044	0.212	0.304		0.002	0.003	0.003		0.262	0.145	0.137	
0630-0700	0.015	0.027	0.050		-0.002	-0.003	-0.005		0.013	0.013	0.018		0.016	0.021	0.078		0.002	0.003	0.005		0.060	0.049	0.102	
0700-0730	0.054	0.066	0.031		0.000	-0.001	-0.008		0.036	0.031	0.061		0.040	0.152	0.086		0.006	0.006	0.006		0.346	0.251	0.255	
0730-0800	0.101	0.083	0.077		0.010	0.013	0.019		0.075	0.076	0.086		0.072	0.096	0.066		0.018	0.018	0.015		0.478	0.453	0.536	

4. Summary

More than 100 hr of sonic anemometer data have been collected simultaneously at 2 and 5 m AGL from five different (200 m apart) locations on a straight N-S path during the CASES-99 field experiment (October 1999). This report is essentially a documentation of the collected sonic anemometer data that is very useful for any serious investigator to study the interaction between the terrain and the near surface boundary layer.

With the exceptions of the data sets collected from tower T5, which has been declared useless due to too many spikes, and the 2-m level air temperature measurements, which appeared unrealistic due to inappropriate field calibration of the sonic anemometers, the comparison results between the two levels on tower T3 have revealed that the data from tower T3 are self-consistent and of considerably high quality. In addition, the intercomparison of the data at the 2-m level among the remaining four towers further indicates the good quality of ARL's sonic anemometer data. It also points out several interesting features. One of these features is the microscale variation of wind field as well as turbulence statistics. This is really a challenge for further data analyses and theoretical study.

ARL's processed/filtered sonic anemometer data sets have been submitted to the CASES-99 central site for cataloging and distributing. Interested users can obtain this data freely through the CASES-99 data management web site at http://www.joss.ucar.edu/cases99. Parts of the results of this analysis have been presented at the CASES-99 Workshop, Boulder, CO, 26–28 March 2001. This report provides users further insights on the data quality and clues for further analysis of the data and study of the stable atmospheric boundary layer.

Acknowledgments

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Acronyms and Abbreviations

ARL   U.S. Army Research Laboratory

CASES-99   Cooperative Atmosphere-Surface Exchange Study-1999

IOP   Intensive Observation Period

AGL   Above Ground Level

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The Cooperative Atmosphere-Surface Exchange Study conducted near Leon, KS in October 1999 (CASES-99) is a multidisciplinary effort to study the interaction of the lower atmosphere with the land surface. Seven three-axis sonic anemometers from the U.S. Army Research Laboratory were deployed on five towers during the CASES-99 field campaign. Each of them has collected more than 100 hr of data. This report describes our data collection and processing details, and provides preliminary analyses from the intercomparison of sonic measurements. One of the interesting results of the intercomparison appears to be the microscale (on the order of 1 km) variability of wind field and turbulence characteristics, which is worthy of further study.

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